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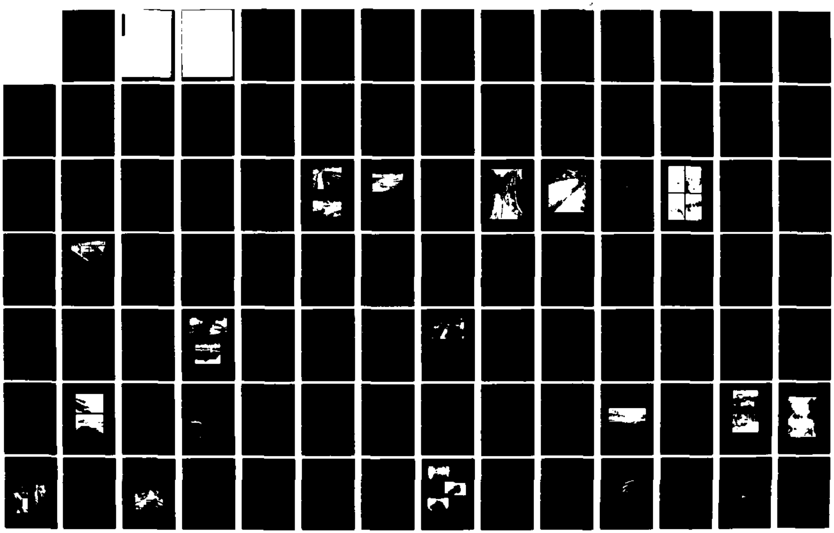

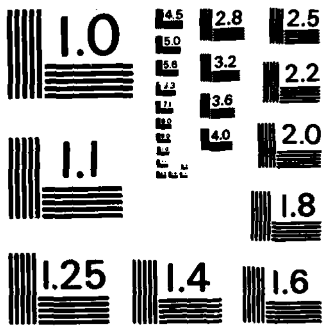
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This report identifies factors and constraints in design and construction of waterways projects affecting environmental quality. Waterway projects covered in this report include channel modifications for both flood control and navigation, dikes, streambank protection, and levees. Locks and dams and flood control dams are not addressed. Flood-control channel modifications include clearing and snagging; channel enlargement, alignment, and relocation; and channel stabilization using grade-control structures or streambank protection.
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20. ABSTRACT (Continued).

The information presented in this report was collected from literature reviews, personal interviews, and visits to Corps of Engineers (CE) field offices and waterway projects. Design and construction practices for each major project type are summarized and environmental impacts are identified. Recent developments in design and construction practices to reduce adverse impacts and ongoing relevant research are reviewed.

Adverse environmental impacts of flood-control channel modification include loss of valuable habitats and habitat diversity, channel instability, reduction of aesthetic value, water quality degradation, and undesirable hydrologic changes. The severity and nature of environmental impact varies considerably from project to project. Methods to reduce adverse impacts include stream restoration, artificial instream structures, modified channel cross sections, and management of cutoff meanders.

Immediate and eventual losses of backwater habitat are a major impact of navigation channel modification projects.

The major environmental impact associated with dikes is the reduction in water surface area and loss of habitat diversity due to sediment accretion in the dike field. In some situations, the rate of sediment accretion may be reduced by constructing notches or gaps in the dikes.

Major adverse effects of streambank protection include loss of riparian vegetation and reduction in the rate of channel migration. Innovative streambank protection designs that reduce adverse impacts feature vegetation and combinations of structure and vegetation.

The major environmental impact of levees is related to their purpose: the creation of drier conditions on the landside of the levee is frequently associated with land use changes. Recent efforts to incorporate environmental considerations in levee projects include management of vegetation on and around levees for wildlife and aesthetics and recreational features.

## EXECUTIVE SUMMARY

The objective of Work Unit VIB of the Environmental and Water Quality Operational Studies (EWQOS) is to provide new or improved design and construction guidance to achieve environmental quality objectives while simultaneously satisfying project purposes. This report documents the first step in developing such guidance: the identification of factors and constraints in design and construction of waterway projects affecting environmental quality and determining areas where improved guidance may be developed.

Waterway projects covered in this report include channel modifications for both flood control and navigation, dikes, streambank protection, and levees. Locks and dams and flood control dams are not addressed. Information presented in this report was collected from literature reviews, personal interviews, and visits to Corps of Engineers (CE) field offices and waterway projects.

Flood control channel modifications include clearing and snagging; channel enlargement, alignment, and relocation; and channel stabilization using grade control structures or streambank protection. Adverse environmental impacts include loss of valuable habitats and habitat diversity, channel instability, reduction of aesthetic value, water quality degradation, and undesirable hydrologic changes. The exact nature and severity of environmental impact varies considerably from project to project. Existing designs that attempt to reduce adverse impacts may be categorized as stream restoration (selective clearing and snagging with manual tools and small equipment), the use of artificial instream structures to increase habitat diversity, modified channel cross sections, and management of cutoff meanders. More information is needed on the cost, hydraulic considerations, and environmental effects of all of these methods.

The environmental impacts associated with navigation channel modifications have not been as clearly defined as the impacts of modifying smaller streams, mainly because biological studies of larger streams are more costly and difficult. Findings of EWQOS Projects V and VIIB

(Waterways Field Studies) should provide useful information about large river ecology and the effects of modification. Immediate and eventual losses of backwater habitat (and thus a reduction in overall habitat diversity) is a major impact of some navigation channel modification projects. Cutoff meanders, for instance, are frequently isolated from the river and filled in by sedimentation. A river channel maintained in a fixed alignment is not free to migrate and create new backwater areas as old ones fill in.

Dikes are free-standing structures, usually of quarry-run stone, placed in a river channel to constrict the flow to a narrower, deeper channel. Dikes reduce the need for dredging and maintain the channel in a desirable alignment. Prior to filling with sediment, dikes and dike fields provide valuable habitat for fish and macroinvertebrates. The major environmental impact associated with dikes is the reduction in water surface area and the loss of habitat diversity due to sediment accretion in the dike field. The rate of accretion varies widely from one river system to another, and dike fields which remain open due to natural or man-made causes continue to provide valuable habitat. Some CE districts have experimented with cutting notches or gaps in dikes to allow flow to scour sediments and maintain the shallow water areas in the dike fields. The results of cutting notches are site and stream specific. Several ongoing studies are addressing the effects of dike notching, the hydraulic effects of various dike design parameters, and the relationship of the dike and dike field habitats to the riverine community. These studies will furnish input to latter stages of Project VI.

Streambank protection is the application of structure, engineering materials, or vegetation to the banks of a stream to control streambank erosion. Streambank erosion is a natural process that may be accelerated or decelerated by the activities of man. Research on the causes of streambank erosion and streambank protection methods is being done by the CE under the Section 32 Program. Additional work is needed to incorporate environmental considerations into streambank protection design and construction. Major adverse environmental impacts of streambank protection include loss of riparian vegetation and reduction in the rate of

channel migration. Bank stabilization can improve water quality by reducing sediment concentrations, and some types of bank protection provide substrate for macroinvertebrates and cover for fish. Innovative designs that reduce adverse impacts include the use of native flood-tolerant vegetation and combinations of vegetation and structure. Design of streambank protection projects should include consideration of both local and basin-wide effects on riparian vegetation and stream morphology.

Levees are earthen embankments constructed adjacent to streams that provide flood protection from seasonal high water. The major environmental impact of levees is related to their purpose: the creation of drier conditions on the landside of the levee is frequently associated with land use changes. Levees also have an effect on flood elevations and peak discharges, but the significance of these effects is debatable. Recent efforts to reduce the environmental impacts of levee projects include management of vegetation on and around levees for wildlife, aesthetics, and recreation. Ongoing field studies are being conducted to examine the relationship of the borrow pits to the riverine ecosystem.

## PREFACE

This report was prepared as part of the Environmental and Water Quality Operational Studies (EWQOS) Task VIB, Design and Construction Techniques for Waterway Projects. The EWQOS program is sponsored by the Office, Chief of Engineers, and is assigned to the U. S. Army Engineer Waterways Experiment Station (WES), under the purview of the Environmental Laboratory (EL).

The study was conducted during the period September 1977 to September 1980 by members of the Water Resources Engineering Group (WREG), Environmental Engineering Division (EED), EL. Principal among these were Mr. F. Douglas Shields, Jr. and Mr. Michael R. Palermo, Chief, WREG. Significant contributions to the study effort were made by Ms. Patricia A. Spaine, Mr. Michael R. Walsh, Mr. J. D. Westhoff, and the late Mr. Thomas K. Moore, all formerly of the WREG. This report was written by Messrs. Shields and Palermo.

A large portion of the study was performed under the direct supervision of Dr. R. L. Montgomery, Special Technical Assistant, EED. The study was performed under the general supervision of Mr. A. J. Green, Chief, EED; Dr. Jerry Mahloch, Program Manager, EWQOS; and Dr. John Harrison, Chief, EL.

The Commanders and Directors of WES during this study were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE, The Technical Director was Mr. Fred R. Brown.

This report should be cited as follows:

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## CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| acres | 4046.873 | square metres |
| cubic feet | 0.02831685 | cubic metres |
| cubic yards | 0.7645549 | cubic metres |
| feet | 0.3048 | metres |
| inches | 2.54 | centimetres |
| miles (U. S. statute) | 1.609347 | kilometres |
| pounds (force) | 4.448222 | newtons |
| square feet | 0.09290304 | square metres |
| square miles | 2.589998 | square kilometres |

# ASSESSMENT OF ENVIRONMENTAL CONSIDERATIONS IN THE DESIGN AND CONSTRUCTION OF WATERWAY PROJECTS

## PART I: INTRODUCTION

### Background

1. The U. S. Army Corps of Engineers (CE) is responsible for the planning, design, construction, and operation of water resources projects throughout the United States. Historically, the environmental effects of these projects were of minimal concern to either the CE or the general public. Projects were planned and designed to develop specific resources. Economic evaluation procedures did not include consideration of the effect of the project on environmental quality. However, in recent years a national awareness of the environment and environmental impacts has developed. Concern for the present and future state of the environment has produced various legislative actions and numerous CE directives, publications, and regulations.

2. Waterway projects include dikes, revetments, levees, and channel modifications for flood control and navigation purposes. Locks and dams and flood control dams are not covered in this report. The possible effects of these works may include wetlands drainage, loss of native vegetation, cutoff of oxbows and meanders, water table drawdown, increasing erosion and sedimentation, and change of aesthetics. Other possible effects on the aquatic system may include loss of aquatic habitat, productivity, and species diversity, or invasion by undesirable plant or animal species. Development of improved design and construction procedures for such projects may result in the elimination or reduction of adverse environmental impacts. New or improved guidance for the design and construction of waterway projects to achieve environmental quality objectives while simultaneously satisfying project purposes is required but not generally available. The development of such guidance is the objective of Work Unit VIB of the Environmental and Water Quality Operational Studies (EWQOS).

3. The intended audience of this report includes those outside the CE who may not be familiar with the general procedures for planning, design, and construction of CE Civil Works projects or the nature and purpose of waterways projects. For this reason, basic descriptions of the projects and how they are designed and constructed are included in addition to discussion of environmental aspects.

## Purpose

4. The purposes of this report are to assess the constraints and factors in design and construction of waterway projects affecting environmental quality, evaluate their relative importance, and to identify areas in which improved guidance for design and construction may be developed.

## Scope

5. Waterway projects specifically addressed by this report fall into four broad categories: channel modifications for flood control and navigation, dikes, streambank protection, and levees. Environmental considerations especially for the construction phase of the project which are unrelated to specific design features are not covered in detail, primarily due to the availability of several sound references which deal with environmental protection at construction sites (U. S. Environmental Protection Agency 1975, Animoto 1977). There are some special considerations associated with waterway project construction, of course, such as temporary impacts on aquatic and terrestrial life. Temporary impacts related to project construction can often be avoided or minimized by carefully scheduling construction events. For example, conflicts with spawning or migration can sometimes be avoided by scheduling. CE planning procedures and environmental policies are briefly outlined in Part II of this report to supply background information relevant to the discussions of environmental considerations in design and construction. The conclusions and recommendations of the report deal

with development of improved environmental guidance for channel modifications, dikes, streambank protection, and levees.

## Organization of the Report

6. The parts of this report dealing with channel modifications, dikes, streambank protection, and levees all follow the same general format. Each part begins with a brief introduction and ends with a summary. After the introduction, purposes and descriptions of the type of project under consideration are presented. Existing CE design and construction practices are reviewed, and the environmental impacts of each project type are discussed. The relationship between waterway project design and construction practices and environmental impacts are explored and environmental considerations in the planning and design of these projects are discussed. Each part also presents recent developments in design and construction methods that reduce adverse environmental impact and a brief review of relevant ongoing research.

## Study Approach

7. The conclusions drawn in this study are based on reviews of CE design guidance, literature reviews, and field visits to CE field offices, and selected projects. The initial phase of the work consisted of comprehensive reviews of available literature to identify constraints and factors for the design and construction of waterway projects. The reviews included examination of design manuals and other available design guidance and criteria now in use by the CE and other Federal and State agencies (Thackston and Sneed 1980). Related research conducted by the Environmental Protection Agency (EPA), U. S. Department of Agriculture Soil Conservation Service (SCS), and others was also reviewed to determine potential application to CE projects. The literature reviews were aimed at determining the relationship of various design factors and constraints to environmental quality objectives. In addition to literature reviews, visits were made to several CE District and Division

Offices actively involved in the design and construction of waterway projects. This allowed evaluation of additional information gained by practical experience in various regions and under various conditions. Field sites for existing and proposed projects were also visited.

8. Although no field studies were conducted as part of this study, results of field studies conducted as part of other EWQOS projects that deal with the environmental effects of waterway projects and any other relevant, available field data will be used in subsequent development of improved guidance for waterway project design and construction.

# PART II: GENERAL ENVIRONMENTAL POLICY AND GUIDANCE FOR DESIGN AND CONSTRUCTION

## Environmental Considerations in Water Resources Development

### The planning process

9. Water resources development may be thought of as occurring in four phases: planning, design, construction, and operation. The planning process typically occurs over a period of many years. Planning generally begins with the definition of goals or objectives for water resource developments both regionally and locally or the identification of problems to be solved. Various alternatives for meeting these goals are then formulated and evaluated.

10. The planning process usually proceeds through a series of iterations, with plans growing more and more specific. The outcome of the planning processes is a specific plan to meet the stated goals or solve the given problems. The final plan will usually include the type, magnitude, cost, impacts, and location of the proposed project. For instance, after consideration of several alternatives, planners might decide that a reservoir would be the best alternative to control flooding of a particular area. Planners would also determine the site of the reservoir and how much storage it would provide, its cost, and the expected reduction in flood damages.

11. Most decisions which have major environmental implications occur in the planning process. Design and construction of the project generally control less of the nature and magnitude of the environmental effects (Thackston and Sneed 1980).

### Historical perspective

12. Although the decisions made in the planning process usually have profound environmental implications, the environmental effects of various alternative plans have not always received the detailed considerations they do today. Water resources planning in the United States evolved from rather primitive efforts to processes that weighed the economic merits of alternative plans. Comparison of alternatives based

on economic criteria has recently yielded to a currently evolving process which fully integrates environmental, social, and economic factors (Schad 1979). Prior to the 1930's, decisions regarding water resources development were made based on the engineering judgment of a few dominant individuals. Project funding was based largely on political criteria or qualitative economic arguments. Beginning with the Flood Control Act of 1936, Federal agencies were required to perform an economic analysis of project benefits and costs. Although legislation was also passed requiring agencies to consider intangible factors (such as environmental quality) in project planning, these factors actually received little consideration, probably because they could not be quantified and included in a benefit-cost ratio (Linsley 1979).

13. The passage of Public Law 91-190, the National Environmental Policy Act (NEPA), in 1969 required the preparation of a detailed statement describing the environmental impact of the proposed action, and alternatives to the proposed action. The approved procedure for preparation of environmental impact statements (EIS) included a review and coordination process that allowed other Government agencies and the general public to review and comment on the planning decisions. The EIS was required in addition to benefit-cost analysis. The environmental implications of planning decisions thus became more obvious.

14. Planning procedures for water resources projects were revolutionized in 1973 by introduction of new regulations for planning by the Water Resources Council entitled, "Principles and Standards for Planning Water and Related Land Resources." These regulations required that the impacts of a project on national economic development, environmental quality, regional development, and social well-being be assessed and tabulated in a system of accounts. Environmental factors must be considered from the very outset of the planning process and major decisions and tradeoffs affecting environmental factors are made prior to detailed design (Ortolano 1979). A modified form of the Principles and Standards entitled "Principles and Guidelines" has recently been proposed to replace the Principles and Standards. The Principles and Guidelines allow increased flexibility for planning agencies, while still retaining the

four-account system. National economic development is the chief planning objective under the newer regulations, as opposed to a joint objective of environmental quality and economic development. A series of Engineer Regulations and Pamphlets (U. S. Army, Office of the Chief of Engineers 1981) provides guidance for implementing the "Principles" regulations.

15. Many CE projects currently under construction or in the later stages of planning were planned prior to the passage of NEPA and institution of the new Principles and Standards. Impact statements have been prepared for nearly all CE projects completed after NEPA, but the applicability of the new procedures based on Principles and Standards to ongoing projects is determined on a case by case basis.

## General Environmental Guidelines for Design and Construction

16. Formal guidance for consideration of environmental quality now exists in several forms. However, this guidance is largely conceptual in nature, telling only what environmental resources should be enhanced or preserved and outlining only general procedures. Little detailed technical guidance now exists regarding how to accomplish mandated goals and objectives.

17. General guidance now in effect for consideration of environmental quality in project design and construction is contained in the following Engineer Manuals (EM's), Engineer Pamphlets (EP's), and Engineer Regulations (ER's).

- a. EM 1110-2-38 Environmental Quality in Design of Civil Works Projects (3 May 1971).
- b. EP 1105-2-500 Environmental Program (June 1973).
- c. EP 1165-2-500 The Army Corps of Engineers and Environmental Conservation (15 April 1971).
- d. EP 1165-2-501 Environmental Policies, Objectives, and Guidelines for the Civil Works Program of the Corps of Engineers (29 October 1976).
- e. ER 1105-2-129 Preservation and Enhancement of Fish and Wildlife Resources (15 August 1973).

*f*. ER 1165-2-2 Consideration of Aesthetic Values in Water Resource Development (6 March 1967).

*g*. ER 1165-2-116 Pollution Control at Civil Works Projects (28 February 1968).

*h*. ER 1165-2-28 Corps of Engineers Participation in Improvements for Environmental Quality (30 April 1980).

18. Both the purpose and content of the above documents vary greatly. Collectively, the content of these documents spells out overall Corps policy regarding environmental quality. More detailed discussion of the content of selected guidance documents is found in the following paragraphs.

### Policies, objectives and guidelines for the Civil Works Program

19. The CE is committed to implementing the NEPA of 1969, other environmental statutes, and the environmental guidelines of the Executive Branch of Government. These policies, objectives, and guidelines will be or have been incorporated into appropriate ER's to assure full consideration in planning, development, and management of water and related land resources.

20. Implicit in the Corps policies are four general environmental objectives (U. S. Army, Office of the Chief of Engineers 1976):

*a*. To preserve unique and important ecological, aesthetic, and cultural values of our national heritage.

*b*. To conserve and use wisely the natural resources of our nation for the benefit of present and future generations.

*c*. To restore, maintain, and enhance the natural and man-made environment in terms of its productivity, variety, spaciousness, beauty, and other measures of quality.

*d*. To create new opportunities for American people to use and enjoy their environment.

### General environmental guidelines

21. The above objectives translate into general environmental guidelines for design and construction of civil works projects. These guidelines are listed in EP 1165-2-501 (U. S. Army, Office of the Chief of Engineers 1976).

22. Design. With respect to design and activities, the following general guidelines apply:

a. Reevaluate the findings, conclusions, and recommendations developed during preauthorization planning (including authorization recommendations) in the light of current environmental objectives and programs.

b. Consult with other governmental agencies and the public, keeping them fully and continuously informed of progress, and obtaining, considering, and using their ideas, views, and recommendations.

c. Integrate specific environmental considerations into the planning and design of all project features to ensure that qualitative values associated with the project are enhanced, preserved, or maintained.

d. Ensure the evaluation of fish and wildlife habitats, particularly those that are critical to threatened and endangered or otherwise significant species, taking appropriate action to comply with pertinent laws and the fish and wildlife provisions of the authorized plan.

e. Attempt to mitigate unavoidable disruptions.

f. Make the project as aesthetically pleasing as possible, seeking to harmonize its features with the surrounding natural and man-made environment.

g. Review and keep current the environmental assessment and, if needed, update, supplement, or revise the environmental impact statements.

h. Ensure that all known cultural, historical, and archeological features, sites, structures or artifacts are inventoried and evaluated.

i. Prepare a project Master Plan for developing and administering project resources.

23. Further guidance with respect to environmental quality considerations in design is provided by EM 1110-2-38 (U. S. Army, Office of the Chief of Engineers 1971b), which states that maintenance and improvement of the environment shall be treated equally in all respects with other established objectives in the design of Civil Works projects. The objectives of this policy are to preserve certain water and related resources and amenities that have ecological, cultural, aesthetic, or other values which make them significant in terms of environmental quality.

24. Environmental quality design considerations described in

EM 1110-2-38 include the use of designs compatible with the natural environment to preserve visual and human-cultural values, continuous reevaluation of design approaches to include evolving environmental principles, and encouragement of innovative design approaches to minimize adverse impacts or restore environmental values.

25. Construction. General guidelines for construction are as follows (U. S. Army, Office of the Chief of Engineers 1976):

a. Maintain a dialog with the public to foster understanding and reduce the impact of construction operations.

b. Review the environmental assessments and impact statements and revise as required.

c. Ensure that plant layout and locations of construction road and equipment areas minimize damage to the natural environment and impact on the public.

d. Prevent unnecessary destruction of vegetation, construction scars, and other disruptions at the site.

e. Protect from damage known historical, archeological, or cultural objects, structures, or sites.

f. Minimize the harmful effects of dredged material and solid waste disposal, water pollution, and noise and air pollution.

g. Restore construction sites to near their natural or other desirable condition.

## Inclusion of environmental quality features

26. ER 1165-2-28 (U. S. Army, Office of the Chief of Engineers 1980a) provides guidance for including environmental quality measures in CE water resources development plans. The regulation states that separate measures to enhance, preserve, or restore environmental quality may be recommended to take advantage of opportunities created by the planned development. Such features may be justified on the basis that combined economic and environmental benefits outweigh combined costs. Cost sharing arrangements for unusual environmental features that are not specified by existing legislation are determined on a case by case basis and are usually based on analogy with similar Federal programs.

## Fish and wildlife

27. ER 1105-2-129 (U. S. Army, Office of the Chief of Engineers

1973b) prescribes policies and procedures for consideration of the preservation and enhancement of fish and wildlife resources in planning and developing water resources projects. The regulation outlines procedures for compliance with Public Law 85-624, the Fish and Wildlife Coordination Act. Improvements or additions to water resources projects may be included if benefits derived exceed costs and such benefits cannot be produced as economically by other means, such as a separate fish and wildlife project.

Aesthetic values

28. Aesthetic values may be considered under policies outlined by ER 1165-2-2 (U. S. Army, Office of the Chief of Engineers 1967a). The regulation states that enhancement of natural beauty may be made a project purpose where cost of related improvement is warranted by aesthetic values created. Tangible benefits such as increased recreational use may be directly considered. Intangible aesthetic values may also be considered on a judgmental basis.

## Summary

29. CE policy mandating consideration of environmental quality in design and construction of Civil Works projects is contained in various EM's, EP's, and ER's. Extensive guidance now exists concerning environmental goals and objectives, general procedural matters, encouragement of new and innovative design procedures, consideration of wildlife, cultural and aesthetic resources. However, there is a shortage of specific design and construction guidance to implement these environmental policies.

30. The type and degree of environmental impacts associated with Civil Works projects are largely determined by decisions made during the planning process. Therefore, new approaches to design and construction to enhance environmental quality should be considered during the planning process as well as during the detailed design and construction phases of a project. Thus, the following parts of this report will be of use to personnel involved in planning as well as design and construction.

# PART III: CHANNEL MODIFICATIONS

## Introduction

31. Channel modifications are alterations made to the channel, banks, or overbank areas of a stream that influence or modify channel width, depth, or sinuosity. The term channel modifications in the broadest sense includes clearing and snagging, channel enlargement, channel alignment, cutoff of meanders, channel lining, bank stabilization, dredging, and construction of constricting dikes and levees. Various terms are used synonymously with channel modification and there are some variations in connotation. Channel improvement is an engineering term which emphasizes the flood control and navigation benefits of modification projects. Channelization is most frequently used in reference to the enlargement and alignment of nonnavigable streams, although it is occasionally used in reference to a navigable stream. Channel alteration and stream alteration are additional synonyms. Channel or stream restoration are terms used to describe processes to restore the maximum flow-carrying capacity of a partially obstructed stream channel without significant enlargement or alteration of the channel. Stream improvement refers to measures designed to improve the fishery resources of nonnavigable streams. River training refers to an array of measures used on navigable streams to control floods and maintain a navigation channel by influencing morphologic development.

32. Channel modifications covered in this Part include clearing and snagging, channel enlargement, channel alignment, cutoff of meanders, and channel lining. Most types of channel modification applied to navigable streams are addressed elsewhere. Dikes are discussed in Part IV of this report, bank stabilization in Part V, and levees in Part VI. Environmental considerations associated with dredging are addressed at length in other reports (Herner and Company 1980). Locks and dams and flood control dams are not covered in this report.

33. This Part identifies factors and constraints in the design and construction of channel modification projects using the following

approach. First, the purposes of channel modification are examined and channel modification projects are described, along with a brief discussion of construction methods. Current design procedures are summarized. The findings of several major documents on the environmental impacts of channel modification are presented in summary form. Next, the mechanisms which produce these environmental effects are explored by examining the physical and biological characteristics of unaltered streams, and design decisions are linked to environmental changes. This Part concludes with an overview of existing environmental guidelines for channel modification and innovative designs and construction practices that incorporate environmental considerations.

## Purposes of Channel Modifications

34. Channels may be modified for navigation, drainage, or flood control purposes. Generally flood control channel modifications increase flow-carrying capacity of a stream by reducing the natural resistance and by increasing the cross-sectional area of the channel. The natural resistance of the channel may be reduced by constructing a smoother, straighter, and/or larger channel. Velocities are increased and flood elevations and/or durations are decreased in the modified reach. Channel modifications for navigation purposes attempt to maintain sufficient width and depth, sometimes by concentrating flow into a smaller cross section. The channel is then partially maintained by scour. An effort is also made to control the sinuosity of navigation channels by stabilizing eroding banks and cutting off tortuous bends. Vanoni (1975) gives descriptions of various types of channel modifications used to control sediment transport, and Thackston and Sneed (1980) describe channel modifications found in CE waterway projects.

### Navigation

35. The development of diesel engines and modern towboats has made the use of extremely large tows composed of several barges possible for both upstream and downstream traffic. Natural streams usually must be modified to permit the safe and efficient movement of these tows.

Without channel modification, hazardous conditions might prevail or delays could occur to such an extent that commercial traffic would not be economically competitive with other modes of transportation. Navigation channels must be wide enough for tows to pass one another, deep enough to accommodate shallow-draft vessels (usually 9-12 ft)* and bends wide enough and gradual enough to allow the longest tows to pass (U. S. Army, Office of the Chief of Engineers 1980b).

Drainage

36. Sometimes stream channels are modified to facilitate drainage of agricultural land. Lowering the elevation of the stream channel and increasing its flow-carrying capacity may allow the construction of drains and channels which discharge into the modified stream. Drainage of agricultural land is sometimes desirable because excess moisture can damage crops, encourage certain plant diseases and parasites, and hinder or delay mechanical farm operations. Soil temperatures are also affected by excess moisture (U. S. Dept. of Agriculture Soil Conservation Service 1971). Poor drainage of agricultural lands is sometimes aggravated by poor soil conservation practices and subsequent erosion that lead to severe channel aggradation. This process may occur gradually over several years.

Land-use changes

37. Some channel modification projects result in large-scale land use changes which may or may not have been anticipated. Frequently, the effect is to upgrade land use, but not to change the basic type of activity. For instance, agricultural land may be converted to more intensive production, or deteriorated housing may give way to high cost housing.

38. Land use changes may or may not be a part of the economic justification of a channel project, but changes usually do follow channel modification. Thackston and Sneed (1980) noted that a western Tennessee project authorized for the purpose of protecting existing

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 11.

agricultural lands from flooding had actually resulted in the clearing of considerable bottomland hardwood acreage for soybean production. A study of an SCS project in North and South Dakota concluded that "although the channel's claimed benefits were watershed protection and flood control, the channel permitted and stimulated wetland drainage deleterious to wildlife" (Erickson, Linder, and Harmon 1979).

39. Numerous sources document land use changes associated with flood-control channel modifications. A 1973 report (Arthur D. Little, Inc. 1973) estimated that at least 200,000 miles of waterways have been modified or developed by governments and private citizens in the United States, resulting in the drainage of about 130 million acres of wetlands. A study of aerial photographs of 100 channel projects in Iowa taken before and after channel modification revealed little change in the amount of forest, but did show decreases in herbaceous cover and increased cropland (Best, Varland, and Dahlgren 1978). Forest area along a 19-mile modified reach of the St. Francis River in Missouri decreased by 78 percent (2260 acres) following modification. On a 37-mile unchannelized reach during the same time interval, forest area decreased between 1 and 6 percent (Fredrickson 1979). Similar findings for a project in Minnesota were reported by Choate (1972) and for a project in Oklahoma by Barclay (1978).

## Descriptions of Channel Modifications

### Clearing and snagging

40. A modest improvement in discharge capacity may sometimes be produced by clearing vegetation on the banks and/or removing debris, logs, large rocks, and other obstructions from the channel (Thackston and Sneed 1980). Even overbank areas are sometimes cleared to reduce resistance to flood flows. These impediments retard flow by reducing the effective cross-sectional area of the channel, increasing the channel roughness and trapping additional debris, particularly during high flows. Clearing and snagging may be a general process, or it may be done selectively, with trees and obstructions specifically marked for

removal or preservation. Clearing and snagging may be done with chain saws and log skidders, but it is usually accomplished with bulldozers and other heavy equipment. An alternate approach is to perform clearing and snagging operations from some type of floating plant.

Channel enlargement

41. Channels are sometimes enlarged to increase flow-carrying capacity for flood control or to provide sufficient depths and widths for navigation. Excavation of the channel may range from the removal of a few shoals to an order of magnitude increase in widths and depths. Typically a trapezoidal cross section is used. Design flow rates and sediment transport characteristics influence the choice of a bottom width for the modified channel, while side slopes are determined by the stability of the bank material. Slopes may vary from 4V on 1H for firm rock to 1V on 3H or flatter for silt or clay. Extremely erosive soils require even flatter slopes. Side slopes may also be purposely flattened to accommodate farm equipment or mowing machinery.

42. Since land and excavation requirements are higher for flatter side slopes, steeper slopes may be stabilized with riprap, pavement, or other materials where land values are high. For maximum stability, the entire channel may be lined. Where land values are very high, reinforced concrete channels with vertical sides may be used (Figure 1).

43. During the design process, costs are computed for several proposed designs, and economic trade-offs are made between land costs and construction costs. The presence of buildings, highways, bridges, and rock outcroppings all influence the final design (Arthur D. Little, Inc. 1973).

44. Small channels are usually excavated by draglines or power shovels operating from the bank (Figure 2). If the channel bottom is not too soft, earth moving equipment may operate in the channel itself (Figure 3). An alternate approach is to dig a pilot channel to one side and divert flow so that the major channel may be excavated. This approach works best in the low flow season. Larger channels may be enlarged using conventional dredging equipment.

45. Material excavated or dredged from a channel may be placed in

Figure 1. Reinforced concrete channel (Environmental features include a low-flow channel on the right side and boulder concrete used for the bottom of the channel; photo courtesy of U. S. Army Engineer District, Honolulu)

Figure 2. Stream channel enlargement using a dragline (photo courtesy of the Tennessee Valley Authority)

Figure 3. Stream channel enlargement using crawler pans (photo courtesy of the Tennessee Valley Authority)

a nearby containment area (diked for dredged material) or piled on the banks. Sometimes the excavated material is used to build levees which further increase the capacity of the channel.

46. Channel enlargement and subsequent placement of excavated or dredged material usually involves clearing significant amounts of riparian vegetation. The general practice has been to remove all significant vegetation for several feet on both sides of the channel to allow space for free movement of heavy equipment and disposal of excavated material. For optimum hydraulic efficiency, the completed channel should have sufficient riparian vegetation to stabilize the bank but a minimum projection of vegetation in the channel itself. In this respect well-mowed grass is ideal. Large vegetation hinders hydraulic efficiency by increasing channel roughness. During flood flows, debris tends to lodge in tree stands along the bank, further constricting the flow. Overhanging trees become uprooted during floods and may hang up on downstream

bridge abutments or other constrictions and severely restrict flow. Thus, channel construction has traditionally involved removal of large trees several feet back from the bank to prevent the possibility of a large tree falling into the channel (Arthur D. Little, Inc. 1973).

Channel alignment

47. Natural streams usually follow a meandering path (Figure 4). The theory of stream meandering is treated by Anderson, Parker, and Wood (1975), Morris and Wiggert (1972), and Henderson (1966), among others. The causes of meandering are not well understood, but the general phenomenon has been observed in rivers all over the world. In fact, meandering behavior has been observed in ocean currents including the Gulf Stream and in streams of meltwater flowing across glacial ice (Henderson 1966). Channels which have been completely straightened tend to deposit sediments in alternate bars and thus develop meanders (Figure 5).

48. Alignment or relocation of a stream channel into a straighter configuration is usually done for one of three reasons: (a) to reduce flood elevations, (b) to provide a shorter, less tortuous path for navigation traffic, or (c) to allow structural development (such as a highway crossing) in or around the existing channel. The removal of meanders reduces flood elevations in the straightened reach by reducing flow resistance. Straightening the channel increases bed slope, thus increasing flow velocity.

49. Cutoffs on navigable streams are usually constructed by dredging a pilot channel across the neck of an elongated meander loop. The size, slope, and alignment of the pilot cut are designed so that the cut will gradually scour and capture most or all of the flow of the stream. After the pilot channel is opened, the cut will develop subject to several physical variables (U. S. Army, Office of the Chief of Engineers 1980b). Figure 6 shows the location of cutoffs on the Lower Mississippi River, and Figure 7 shows the development of a cutoff over a 40-year period.

50. Small streams are frequently completely realigned or relocated into reaches which are more or less straight. Construction methods are similar to those discussed above for channel enlargement. The

Figure 4. Natural meandering stream channel, the Klaralven River of Sweden, a typical mature river with confined, developed meanders (photo courtesy of A. Sundborg from Anderson, Parker, and Wood (1975))

Figure 5. Development of meanders within an aligned channel (photo courtesy of North Carolina Wildlife Resources Commission and U. S. Fish and Wildlife Service)

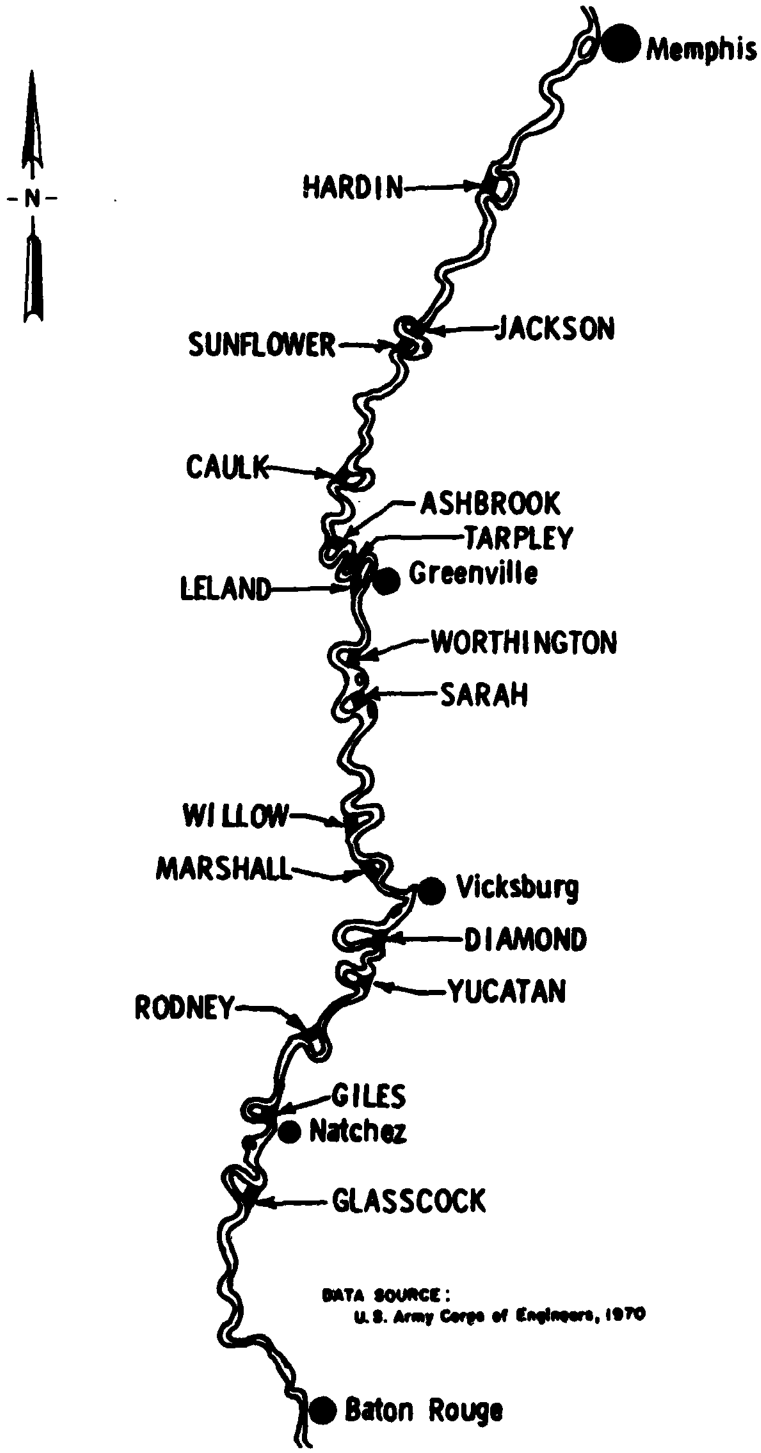



Figure 6. Mississippi River cutoffs

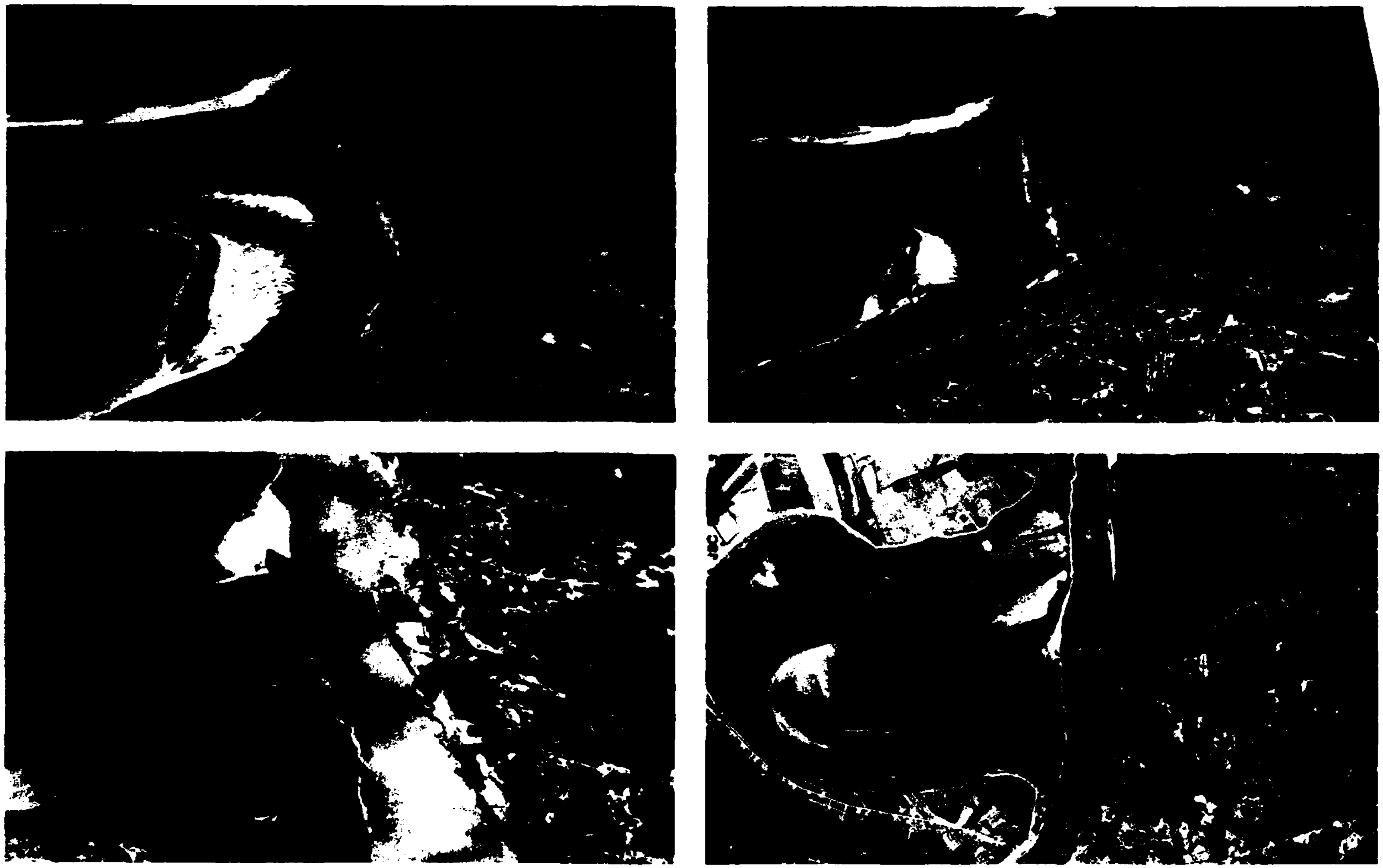


Figure 7. Cutoff development and filling of severed meander, aerial views of Giles Cutoff on the Lower Mississippi River (Note the rapid decline of the severed meander loop; photo courtesy of the U. S. Army Engineer District, Vicksburg.)

use of complete relocation depends on the availability of land adjacent to the natural stream and is usually designed to take advantage of existing bridges and crossings (Arthur D. Little, Inc. 1973).

Channel stabilization

51. A channel of sufficient size and shape to carry the design flow may result in velocities which would scour the channel. Tables of maximum permissible velocities for various materials are available in design manuals (U. S. Army, Office of the Chief of Engineers 1970). In addition to scouring, excessive velocities may result in other forms of channel instability such as bank caving and sloughing, degradation, and channel widening. The CE EM (U. S. Army, Office of the Chief of Engineers 1970) on flood control channel design observes:

> The most common type of channel instability encountered in flood control design is scouring of bed and banks. This results from relatively large discharges, steep channel slopes, and normally limited channel right-of-way widths.

Velocities may be reduced to acceptable levels by the increased frictional drag of a wider, shallower cross section; but sometimes widths sufficient to do this are out of the question (Arthur D. Little, Inc. 1973, Nunnally and Keller 1979). Several methods of ensuring the stability of a given channel are in general use. These measures fall into three general categories: bank protection, channel lining, and grade-control structures (U. S. Dept. of Agriculture Soil Conservation Service 1977).

52. Bank protection. Banks may be protected by such diverse methods as retards, baffles, jetties, vegetation, conditioned earth, riprap, revetments, and other methods. The expense of such measures usually limits their use to certain unstable areas such as the concave sides of bends. A full description of these measures is found in Keown et al. (1977). Environmental considerations in the design and construction of bank stabilization measures are discussed in Part V of this report.

53. Lining. Channels may be completely stabilized by lining or paving the entire cross section. Although lined channels are more expensive to construct than unlined channels of the same size, they can

withstand higher velocities, thus allowing steeper side slopes and narrower channels. Narrow channels are advantageous in urban areas where land costs are high.

54. Lining material. Several different types of lining materials are in common use and selection is usually based on economic and hydraulic factors (U. S. Dept. of Agriculture Soil Conservation Service 1977). Channel linings may be of vegetation for channels with infrequent flow, relatively low velocities, and where a good stand can be developed and maintained. Maintenance of vegetation includes mowing and frequent inspection to detect erosion and loss of cover due to drought, disease, or traffic. Ungrouted riprap may be used for lining channels that are not easily vegetated. Durable impervious linings such as concrete or asphaltic concrete are used in situations where it is necessary to conserve water by eliminating seepage or where high hydraulic efficiency and attendant high velocities are required. Rigid linings are vulnerable to structural failure caused by subsurface erosion. Grouted riprap may be used for short reaches, although it is prone to failure and not recommended for long-term use. Reinforced concrete channels may have either trapezoidal or rectangular cross sections. Other types of linings generally require trapezoidal sections. Banks stabilized with riprap, for instance, should not be steeper than 1V on 2H if machine placed or 1V on 1.5H if hand-placed (U. S. Army, Office of the Chief of Engineers 1970). Keown et al. (1977) identify several other types of erosion control linings such as fabrics, mattresses, cellular blocks, ceramics, gabions, soil cement, etc.

55. Closed conduit. Where a steep slope is available, the entire flow of an open channel may be carried in a closed conduit for short reaches. This structural configuration has a very low land requirement since the flow is completely enclosed and flows under pressure like water in a distribution system (Arthur D. Little, Inc. 1973). Closed conduits have a tendency to back water up when clogged with debris or when the design flow is exceeded. Usually, some type of ponding facility must be built upstream of a closed conduit to prevent these problems.

56. Grade-control structures. Grade-control structures provide

for controlled dissipation of excess energy by means of a vertical drop. Excess energy is dissipated on an apron or in a stilling basin (U. S. Army, Office of the Chief of Engineers 1970). Although there are several different types of grade-control structures, they all are intended to reduce channel grade to avoid scouring conditions.

57. Stabilization structures, grade stabilization structures, or drop structures, as grade-control structures are sometimes called, are also used to control channel grade at overfalls at the upstream end of channels, and at points of confluence with tributary channels. When a segment of stream is enlarged and/or realigned, the hydraulic gradient usually will be steepened through the modified reach. At points of confluence with tributaries the drop in water surface elevation will sometimes be large enough to cause the tributaries and upstream reaches of the main channel to scour until they reach a new equilibrium with the modified channel. This upstream-progressing scour, also called nickpoint recession, head cutting, or unraveling, can be quite severe and may cause channel stability problems over a large area if allowed to proceed unchecked.

58. Grade-control structures may be either closed conduit structures such as culverts, with hooded inlets or drop inlets, or open top structures such as drop spillways and chutes. Figure 8 is an example of an open top grade-control structure. Closed conduit structures are generally limited to relatively small channels, while open top structures may be used in any size channel. Details of various types of grade-control structures are discussed in U. S. Dept. of Agriculture Soil Conservation Service (1977) and U. S. Army, Office of the Chief of Engineers (1970).

59. Another type of structure for stabilizing an erodible channel is the stabilizer, which is a sill or submerged weir designed to limit channel degradation (U. S. Army, Office of the Chief of Engineers 1970). The stabilizer is usually placed normal to the channel center line and traverses the channel invert. A stabilizer crest is placed approximately at the elevation of the existing channel invert with upstream and downstream bed protection which may be covered with backfill.

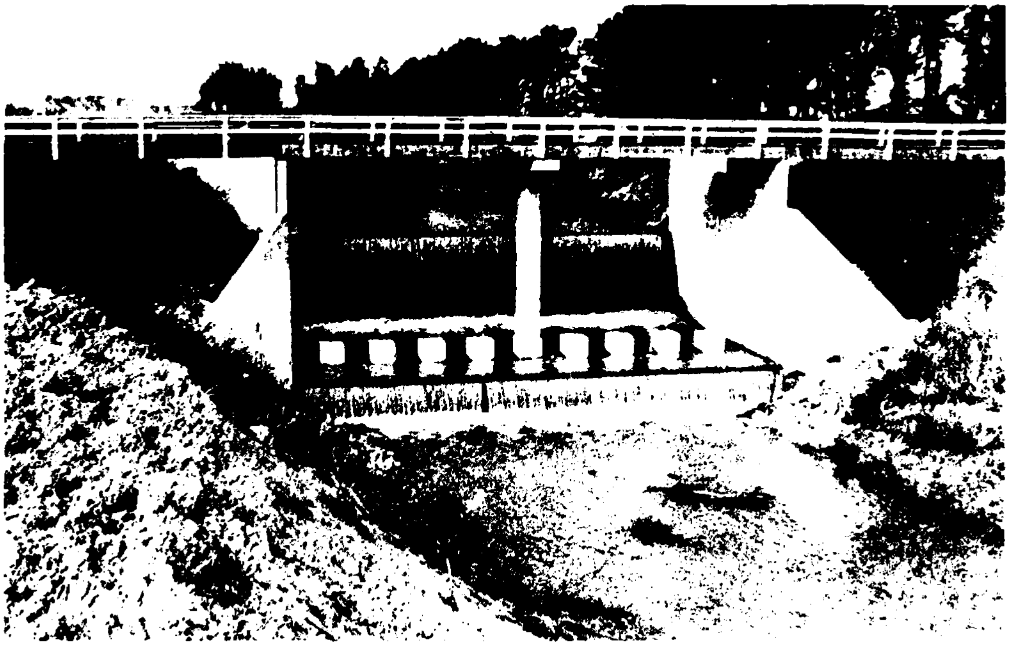
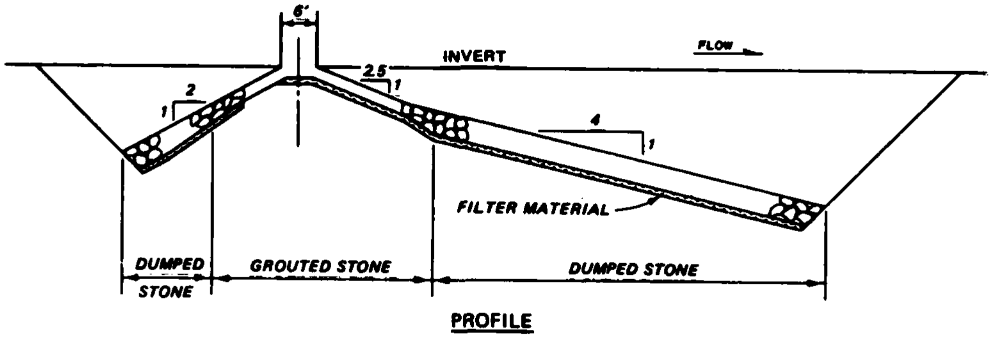


Figure 8. Open top grade-control structure (from Linder (1976))

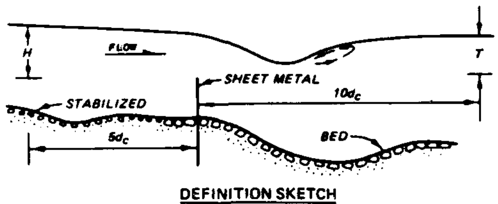
Stabilizers may result in local flow acceleration with upstream and downstream scour. Maximum scour usually occurs during peak discharges. Local bank protection is required in the vicinity of stabilizers to prevent channel migration around the structure. Stabilizers may be made of grouted or ungrouted rock, sheet piling, or concrete sill. Figure 9 shows two types of stabilizers.

Design procedures

60. A brief review of channel design practice based on Arthur D. Little, Inc. (1973), U. S. Dept. of Agriculture Soil Conservation Service (1977), and personal communications is given below. A designer starts by collecting information from field surveys and other sources about the basin in question. Pertinent information includes flow duration data, flood damage elevations, soil characteristics, suspended and bed-load sediment data, and local topography. Design of channels is done in short segments or reaches. Endpoints of reaches are located at points where conditions change suddenly, such as the confluence with a tributary, a change in soil conditions, or a change in slope. Under constant conditions, an arbitrary maximum reach length is assumed. The




a. Rock stabilizer




b. Sheet-piling stabilizer

Figure 9. Channel stabilization structures (from U. S. Army, Office of the Chief of Engineers (1970))

channel design then becomes a problem of sizing the channel, predicting flood heights and durations for various design flows, and checking the channel for stability at flows above, below, and equal to design flows.

61. Trapezoidal cross sections are most frequently used because of ease of construction and hydraulic efficiency. Side slopes are determined based on soil properties, and channel sizing is then completed by selecting an appropriate bottom width to carry the design flow.

62. Once a prospective channel geometry is selected, water surface elevations for various flood flows are computed. Physical characteristics of the channel such as the size of the bed material, topography, bends and presence of pools, riffles, and outcrops are used to estimate roughness coefficients. Roughness coefficients may be estimated based on experience and qualitative evaluations (Chow 1959) or using a systematic procedure (U. S. Dept. of Agriculture Soil Conservation Service 1977). Backwater curve computations are then performed using design flows, roughness coefficients, and channel geometry. The

geometry and roughness of the floodplain are also used to compute backwater curves for overbank flows. The computed backwater curves are compared with flood damage elevations, and additional iterations of the design procedure are performed until the desired levels of protection are achieved.

63. In alluvial channels there are complex dynamic relationships between channel geometry, discharge, and sediment discharge. If the channel is to be constructed in highly erodible material or if large bed loads or suspended sediment concentrations are common in the existing channel, then additional study must be made of the sediment transport characteristics of the modified channel. Computational techniques are available, but the uncertainty of the input data (sediment loads in particular) makes them useful for studying relative effects for a range of conditions rather than making precise predictions.

64. Channel designs are checked for stability as part of the design process. The methods of maximum permissible velocity, regime equations, tractive force, and other methods may all be used to check the proposed design. The prediction of channel stability is difficult because the available methods do not adequately model the complexity of the natural phenomena. More exact methods usually require much more data than is available. In the final analysis, past experience with a particular type of environment may be the most reliable guide to stable channel design.

65. If a channel of otherwise desirable characteristics is deemed unstable, the design may be changed to include grade-control structures, bank protection, or channel lining. As discussed above, economic tradeoffs are made between higher land costs, costs of excavation, and maintenance costs for unlined channels and higher construction costs for lined channels.

66. The hydraulic design of flood control and navigation channels as historically practiced has been almost devoid of environmental considerations. Although some innovation has taken place, the literature yields little quantitative information on the positive environmental effects or the hydraulic effects of such measures. Planners and designers

wishing to incorporate environmental considerations must presently rely heavily on their own intuition and personal resources. The lack of information on the effects of environmental features makes it difficult to make intelligent trade-offs between hydraulic efficiency and environmental quality. The ideal design procedures should produce a channel which transports both water and sediment in an acceptable manner and also enhances environmental quality.

67. Table 1 is an attempt to summarize the preceding information on design of channel modifications. This table presents seven primary factors which may be manipulated subject to certain constraints to achieve primary and secondary objectives. The table is an oversimplification of the design process in that it ignores the complex interrelationships between many of the factors, constraints, and objectives. The table is further simplified by the omission of environmental quality as an objective. All seven stated factors do have an effect on environmental quality, but the problem of environmental considerations is too complex to lend itself to this kind of organization. The effects of the factors on stream and riparian ecosystems will be explored in greater detail below by listing observed environmental effects of existing design and construction practices and relating adverse environmental effects to changes in natural characteristics.

## Environmental Effects of Channel Modifications

### Measurement and documentation of environmental effects

68. One approach to identifying environmental considerations in the design and construction of channel modifications is to examine the adverse and beneficial environmental effects of projects already constructed. Unfortunately, many environmental effects of channel modifications are difficult to measure and document. Stream habitats are constantly changing and are subject to a host of influences. One need only consider the effects that normal climatic variations or the cultural activities or natural events in the basin can have on stream habitats to

Table 1

Simplified Summary of Factors, Constraints, and Objectives

for the Design of Channel Modifications

| Primary Factors | Constraints | Objectives |
|---|---|---|
| Design flow | Damage elevation<br>Upstream and downstream controls | Desired level of flood control or drainage |
| Channel roughness | Bed material<br>Presence of obstructions | Hydraulic efficiency |
| Longitudinal slope and channel invert elevation | Local topography | Channel stability<br>Lowering water surface to facilitate drainage<br>Hydraulic efficiency |
| Cross-sectional shape and area | Constructability<br>Economics--land values | Suitable widths and depths (for navigation)<br>Discharge capacity for desired level of flood control |
| Side slope | Soils--bed material<br>Economics--land values | Channel stability |
| Channel alignment, sinuosity | Available right-of-way<br>Existing structures<br>Input sediment loads | Hydraulic efficiency<br>Channel stability<br>Navigability |
| Use of lining, bank stabilization, and grade-control structures | Economics | Channel stability |

realize how difficult it is to isolate the cause of an observed change. Since streams do change with time, blind comparisons of conditions before and after modification of a particular reach of stream may lead to erroneous conclusions about the effect of modifications. Generally, changes due to natural causes occur at a slower rate than culturally induced change. Therefore, an understanding of changes and variations that normally occur in relatively unimpacted systems is essential.

69. Spatial variations. In addition to temporal change, spatial variations in aquatic habitats also make comparison difficult. Because of the large number of variables involved, environmental effects tend to be site-specific. Comparisons of data from different reaches of the same stream or from different streams may be made, but only if the unique features of each site are first considered. Two adjacent drainage basins may exhibit quite different patterns of geology or land use, and a stream is influenced by events and conditions in its basin. Inland freshwater streams differ both physically and biologically from estuarine streams, and large streams support communities different from small streams. Some streams depend on photosynthetic production of organic matter as a primary energy source, while others rely on importation of organic matter from tributaries or from terrestrial sources such as tree leaves (Marzolf 1978). The composition of the stream community is also strongly influenced by the nature and size of the bed material. Stable substrates composed of large rocks can support a highly productive benthic community. Unstable, sandy streams may be characterized by a less productive benthic community located mostly in and around fallen logs and snags (Hynes 1970).

70. Habitat recovery. Most streams exhibit some tendency to recover from the effects of channelization. The rate of recovery depends on the nature and extent of channelization and the resiliency of the ecosystem. Over a period of years the riparian vegetation grows back, and the stream may begin to develop some vertical relief and meanders. An armor layer of coarse substrate may form in the channel bed. Snags develop, and there is a recovery of floral and faunal numbers and diversity. The process of physical and biological recovery may reduce

hydraulic efficiency to the point that channel modification must be repeated (maintenance) to restore the lost flow capacity. Habitat recovery tends to be set back by maintenance. Therefore, in comparing two or more sites, one should note the recovery time, or the time elapsed since construction or maintenance of the modified channel.

71. Recovery rates for fish and wildlife populations vary significantly from stream to stream and tend to be related to the length of the altered segments, the type of alteration, the proximity of a large river or lake, the species present, and recovery of the physical habitat. Studies of sites in Iowa (King and Carlander 1976), Vermont (Dodge et al. 1976), Montana (Lund 1976), and Utah (Barton and Winger 1973) on altered, short segments (1-2 miles) observed recovery of aquatic populations (fish, drift, or benthos) within 8 months to a few years. Stream improvement structures were used to speed recovery in Utah and Montana. Some streams with long altered sections exhibit very slow recovery. Arner et al. (1976) found only partial recovery of fish populations in a 48-mile segment of the Luxapalila River 52 years after channelization and this was related to the recovery of gravel substrate. In a channelized 5-mile section of the Olentangy River in Ohio, numbers, biomass, and diversity of macroinvertebrates had not recovered after 27 years (Griswold et al. 1978). Golden and Twilley (1976) found that fish biomass and number of species had not recovered after 33 years in a long channelized reach (24 miles) of Big Muddy Creek, Ky. Recovery rates may be influenced by adjoining bodies of water. Griswold et al. (1978) found relatively large and diverse populations of fish in altered streams which were tributary to the Ohio River and Lake Erie.

72. Recovery of bird and mammal populations along altered streams has been found to be related to the amount of riparian vegetation removed and to plant succession (Prellwitz 1976, Arner et al. 1976). Muskrat and beaver populations may also be related to water depths and bank soil types (Arner et al. 1976).

73. The temporal and spatial variations of stream habitats have led some investigators to conclude that truly controlled studies of the environmental effects of channel modifications are not possible.

Integration of experiences from ecologically similar locations should provide the best conclusions about the effects of channel modification and possible remedies.

74. Fish studies. A great many studies of altered streams have focused on fish because of the recreational and commercial uses of freshwater fish. Fish populations are subject to a host of influences, including water quality, populations of lower organisms, and the presence of structure or cover. Since fish are in the higher tropic levels of the aquatic food web, they may be affected by changes in the populations of lower organisms, although some species of fish are opportunistic feeders and can adapt to new food sources. Large changes in fish abundance, size, distribution, density, and species composition have been observed in conjunction with stream alteration. However, insufficient baseline data on biological interactions and a lack of information about the impacts on other stream organisms prevent the exact cause for the changes in fish populations to be determined. Fine-tuning channel designs to accommodate both hydraulic requirements and environmental quality objectives is guesswork without more basic information.

## Observed effects of channel modifications

75. The positive effects of waterways projects center around the main project purposes of drainage, flood control, and navigation. The exact value of these benefits is rarely determined since the study of project costs and benefits is always done prior to project construction and rarely repeated afterwards.

76. Channel modification sometimes changes a particular water quality parameter or some other aspect of the physical habitat in a way normally thought of as favorable. However, these favorable effects tend to be offset or completely overshadowed by attendant adverse effects. For example, a study of seven coastal plain streams in North Carolina found that while natural streams usually suffered stagnation and dissolved oxygen depletion during low-flow season, after channelization the streams tended to have near-saturation dissolved oxygen concentrations throughout the year due to higher velocities and more turbulent

conditions. On the other hand, the channelized streams exhibited higher concentrations of nutrients, higher particulate loads, and higher turbidities than the natural streams (Kuenzler and Mulholland 1977). A study of a coastal swamp watershed, also in North Carolina, concluded that if the channel were modified, the fraction of streamflow contributed by groundwater would increase, and the fraction due to overland runoff would decrease. This change in the water budget would result in higher low flows and perhaps in a decrease in fertilizers, herbicides, and pesticides reaching the stream since these compounds would be retained in the soil. These positive effects would probably be offset by increases in the concentration of sediment and dissolved solids and perhaps by increased temperatures (Winner and Simmons 1977).

Literature synthesis

77. Extensive literature is available on the adverse environmental effects of channel modifications. Most common are studies of modified inland streams not open to commercial navigation, particularly studies of fish populations. Less numerous are studies which present data collected before and after modification, studies on navigable waterways and large rivers, and studies of projects which incorporate environmental features and environmental enhancement measures.

78. Several reports are available which review and summarize the abundant literature on the environmental impacts of channel modifications. Some of these reports are summarized below. Most of these reports present lists of adverse environmental impacts or critical environmental issues. These lists should be read with care, since they do involve broad generalizations of a large number of disparate situations. Certainly not all the effects or issues listed will be found at every site, but usually a few will be. For example, in a study of modified Pennsylvania trout streams, Duvel et al. (1976) found no long-term deleterious effects on water quality, attached algae, benthic fauna, or forage fish populations. However, significant differences were found in trout numbers and size between natural and modified reaches.

79. Another factor which should be used when considering these lists of impacts is redundancy. A list may include both of the items

"land-use changes" and "loss of bottomland hardwoods" when one should be included in the other. The reader should also be aware that the bulk of existing information is derived from studies of streams too small for commercial navigation. Finally, there seems to be a need to establish a hierarchy of effects in order to trace their causes. Some differentiation among primary, secondary, and tertiary effects needs to be made.

80. A synthesis of the adverse environmental effects of channel modifications that are listed by existing literature reviews and broad-based reports (Arthur D. Little, Inc. 1973, Barton and Winger 1973, Darnell et al. 1976, U. S. Environmental Protection Agency 1973, Hill 1976, Johnson et al. 1974, Solomon et al. 1975, and Keeley et al. 1978) provides a general overview of problem areas. Adverse environmental effects may be grouped as follows:

a. Loss or change of aquatic habitat and/or habitat diversity leading to undesirable shifts in production, diversity, density, and/or composition of aquatic communities.

b. Loss or change of terrestrial habitat and/or habitat diversity leading to undesirable shifts in production, diversity, density, and/or composition of terrestrial communities.

c. Increased sediment concentrations and turbidity, bank caving and sloughing, channel aggradation and degradation, head cutting, and other consequences of channel instability.

d. Reduction of aesthetic values of streams and riparian areas.

e. Water quality degradation, principally increasing temperature and sediment concentration.

f. Changes in hydrologic conditions including lowering the watertable, draining wetlands, greater variation of discharge, increased downstream flood stages, intermittent flows, and increasing uniformity of flow conditions (depths and velocities).

## Environmental Impacts and Design Considerations

### Modification-impact relationships

81. The complexity of streams and their biological communities makes it difficult to establish definite cause-and-effect relationships

between impacts and modification. Several authors (Darnell et al. 1976, Arthur D. Little, Inc. 1973, Nunnally and Keller 1979) have attempted to solve this problem by reviewing the physical and biological characteristics of unaltered streams and then deducing the effects of channel modification on the stream and riparian systems. Darnell et al. (1976) express this rationale as follows:

> ...the crux of the environmental protection problem is the basic understanding of healthy environmental systems, recognition of general symptoms of environmental disturbance, and further appreciation of the particular symptoms of specific types of environmental stress.

Much of the discussion below relies on this philosophy.

Clearing and snagging

82. The potential effects of clearing and snagging on stream ecosystems are estimated by Marzolf (1978) using "recent concepts of stream function" instead of field data. Very little field data has been published from studies of streams modified by clearing and snagging only. Clearing is routinely performed in conjunction with most types of channel modification, while some projects consist of clearing and snagging only. The discussion below deals with the impacts of clearing and snagging without more extensive modifications.

83. Removal of the vegetative canopy from the banks of low-order streams may result in decreased shade and resultant higher stream temperatures, decreased input of organic matter such as leaves, and increased photosynthesis in the stream. The decreased input of organic matter probably impacts the macroinvertebrate community severely, although faunal changes associated with clearing and snagging are not well documented. Increased photosynthesis in the stream may shift the trophic state of the stream ecosystem. Dense mats of algae may appear (Gorman and Karr 1978) or the channel may be invaded by rooted vegetation at low flows which constricts the channel at high flows (McCall and Knox 19?8).

84. The removal of snags increases the mean velocity of the stream. This increased current may affect plankton production or erode

away fine sediment which provides substrate for specific kinds of benthic algae. The woody debris removed by clearing and snagging is itself a substrate; sometimes it is the most abundant habitable substrate in streams with unstable sandy bottoms. Sediments may be swept away which provide habitat for rooted plants and associated fauna, which are particularly important in intermediate-order streams (Marzolf 1978).

85. A smoother stream with less obstructions will not retain coarse particulate organic matter (CPOM) such as tree leaves as readily. The CPOM will be swept downstream to deeper streams which formerly received fine particulate organic matter (FPOM). This may upset downstream macroinvertebrate communities, since these organisms are frequently highly selective of food particle size (Cummins 1974). The smaller streams are usually more turbulent and aeration supplies the oxygen demand of decomposing CPOM. If the CPOM is deposited in deeper sedimentary areas downstream which are not adequately aerated, those areas may become anaerobic (Marzolf 1978).

86. Impacts on the macroinvertebrate community will ultimately affect fish populations which depend on the invertebrates for food. The change in food resources may result in reduction of fish populations or a change in species composition--from invertivores to less-desirable herbivores, for instance. Some species of fish may adjust to new conditions if alternate food sources are available.

87. Fish may be adversely affected by the removal of snags which serve as cover and shelter. In a natural stream, fish tend to group around cover and shelter which provide hiding and spawning areas and serve as fixed reference points for orientation and territorial behavior. Some authors (Norton, Timbol, and Parrish 1978, Hynes 1970) suggest that the eddies and regions of calm water produced by snags and obstructions during high flows provide important shelter for fish.

88. Removal of riparian vegetation may have an adverse effect on bank stability, particularly in highly erosive soils. Bank failure may aggravate other types of channel instability.

89. Clearing large amounts of terrestrial vegetation for channel work can also affect terrestrial communities. Since clearing represents

a reduction in available wildlife habitats, populations of birds, mammals, and reptiles will decrease accordingly. Species composition and abundance of riparian mammals are related to abundance and diversity of bank vegetation. Studies in Vermont (Dodge et al. 1976) and Mississippi (Arner et al. 1976) found mammal track counts along natural streams were almost twice as great as mammal track counts along recently channelized streams. Old channelized streams seemed to partially recover riparian mammal populations (Prellwitz 1976, Arner et al. 1976, Dodge et al. 1976). On the other hand, Geier and Best (1980) found that the conversion of woodlands into open communities dominated by herbaceous vegetation benefited several species of small mammals. The abundance and diversity of birds are related to the type and variety of streambank vegetation (Stauffer and Best 1980) and generally increase as plant succession advances (Prellwitz 1976, Fredrickson 1979, Dodge et al. 1976).

90. Planning and design of clearing and snagging operations should include an evaluation of the importance of the canopy to the stream community. The importance of snags as substrate for macroinvertebrates and as shelter and cover for fish should be considered. The preservation or replacement of structure in the stream should be considered. Some thought should be given to the changes in the velocity field of the stream which will be induced by clearing and snagging. An effort should be made to predict the effects of clearing and snagging on bank stability.

91. Specifications may be written to restrict the amount and type of terrestrial vegetation to be removed. Stumps may be left in place to promote bank stability, for example, or nut trees may be left to enhance wildlife habitat. Clearing and snagging then becomes a selective instead of a general process. The type of equipment used is also an environmental consideration that can be controlled by specification. Selective clearing and snagging guidelines are presented in Appendix A.

92. Although exceptions do exist (Barclay 1978), streams which have been cleared and snagged tend to recover their riparian terrestrial communities and ultimately their aquatic communities as the habitat recovers. Maintenance of modified channels generally wipes out the

gains of recovery. Consideration should be given, therefore, to the expected frequency and method of future maintenance.

Channel enlargement

93. Most adverse environmental effects associated with channel enlargement can be related to the use of a uniform cross section. The uniform cross section destroys the natural vertical relief--the pool-riffle sequence. The attendant loss of diversity of depths, current velocities, and substrates reduces habitat diversity. A reduction in habitat diversity may be felt biologically by a reduction in species diversity and/or species composition (Figure 10), a reduction in the size, distribution, and condition of the population (Figure 11), or unnatural seasonal variations in populations (Gorman and Karr 1978).

94. The use of uniform cross-sectional geometries affects the aesthetic value of the modified channel. When channel enlargement is combined with alignment and removal of streambank vegetation, the natural stream loses much of its aesthetic value and appears as a uniform, linear ditch (Figure 12).

95. Enlargement of a stream channel will affect channel stability. An increase in channel width and/or depth may cause changes in slope, sinuosity, or sediment discharge due to the relationship among these variables. Removal of natural armoring can increase scour and downstream deposition.

96. Generally channel enlargement will be accompanied by all of the unfavorable effects of clearing and snagging, since it will include clearing and snagging. An exception would be channel enlargement done with a dredge (Figure 13). Dredging normally requires considerably less destruction of riparian vegetation for equipment access and haul roads. Since dredged material may be pumped long distances, a few large disposal areas can be used instead of many small ones.*

97. Channel enlargement also changes the hydraulic characteristics of the natural channel. Flood flows are typically greater and

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* Letter Report, 16 December 1977, from John E. Henley, Chief, Engineering Division, U. S. Army Engineer District, Vicksburg, to President, Mississippi River Commission.

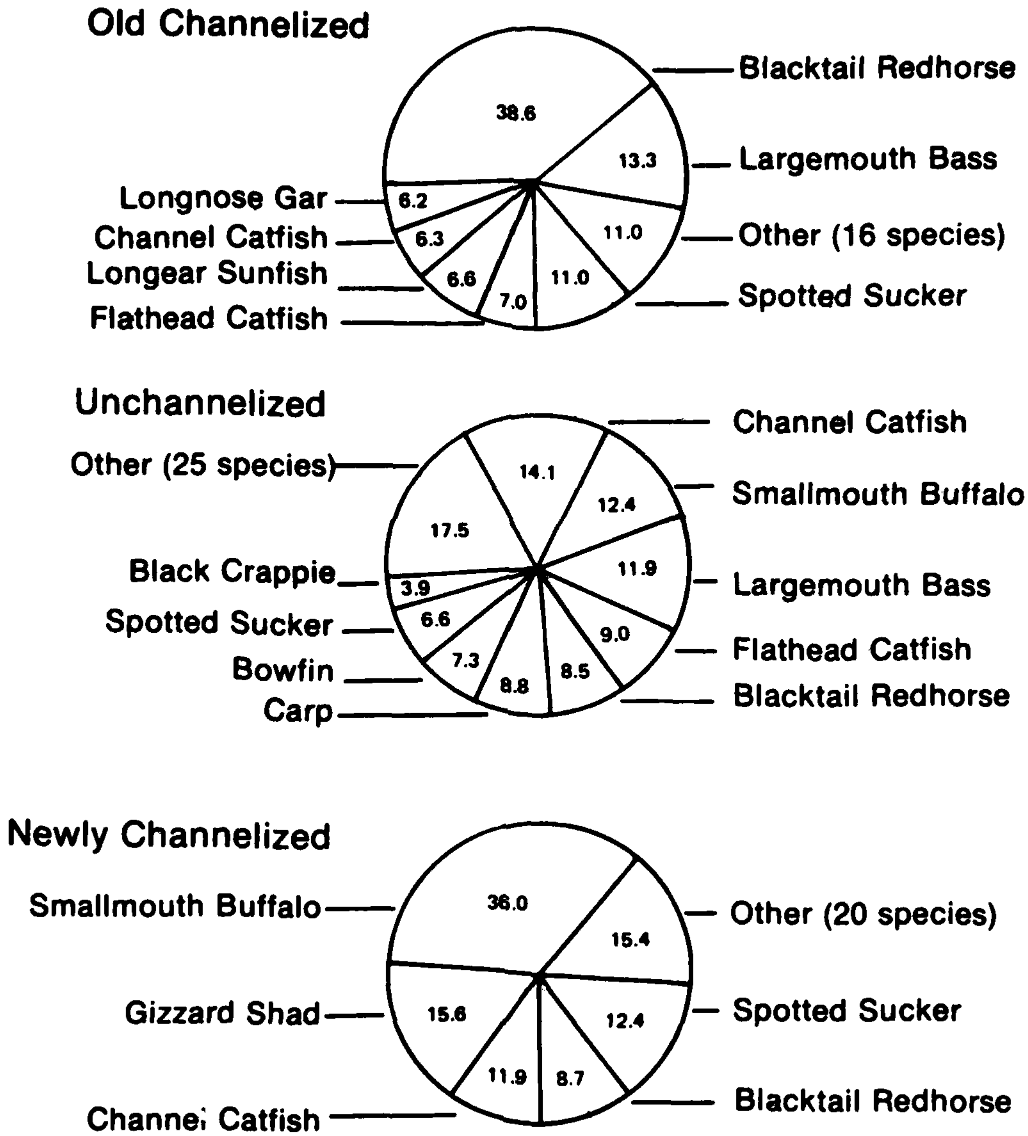



Figure 10. Impact of channel alignment and enlargement on fish species diversity and composition; percentage composition by weight from hoop net, gill net, and electrofishing samples in unchannelized, old channelized (52 years) and newly channelized segments of the Luxapalila River, Miss., between July 1973 and January 1976 (after Arner et al. (1976))

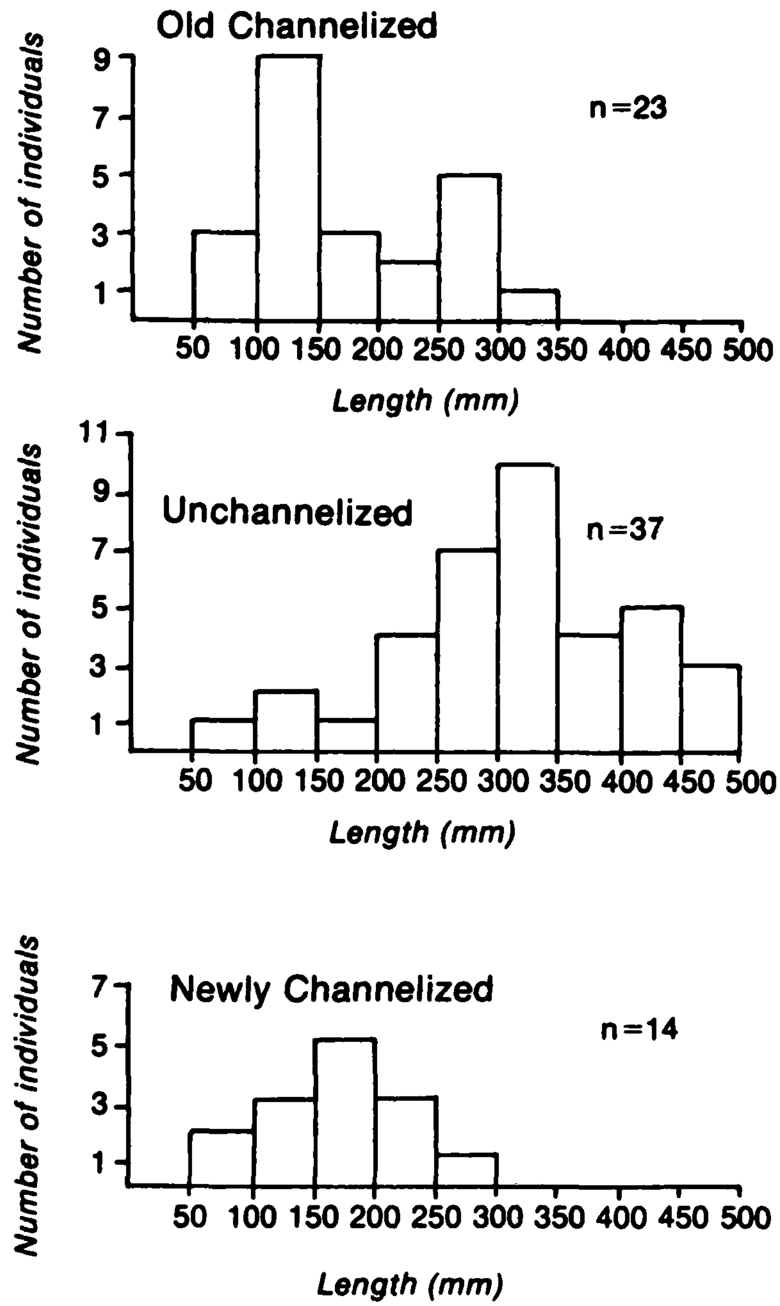


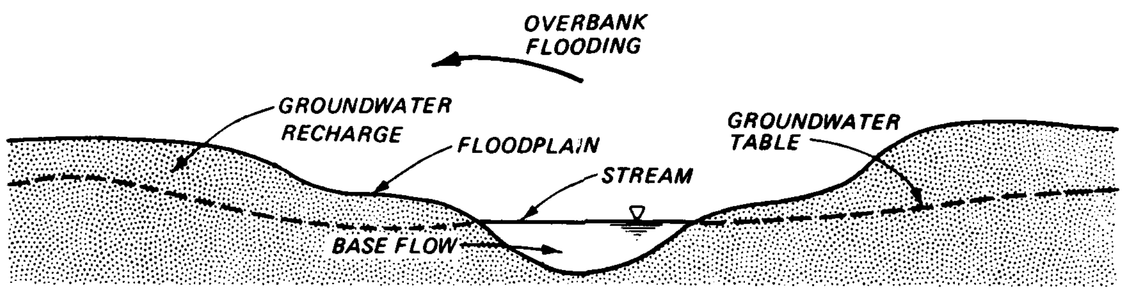

Figure 11. Impact of channel alignment and enlargement on fish size distribution; length frequency of largemouth bass in three segments of Luxapalila River, Miss. (after Arner et al. (1976))

Figure 12. Impact of channel modification on aesthetic resources (photo courtesy of the U. S. Fish and Wildlife Service)

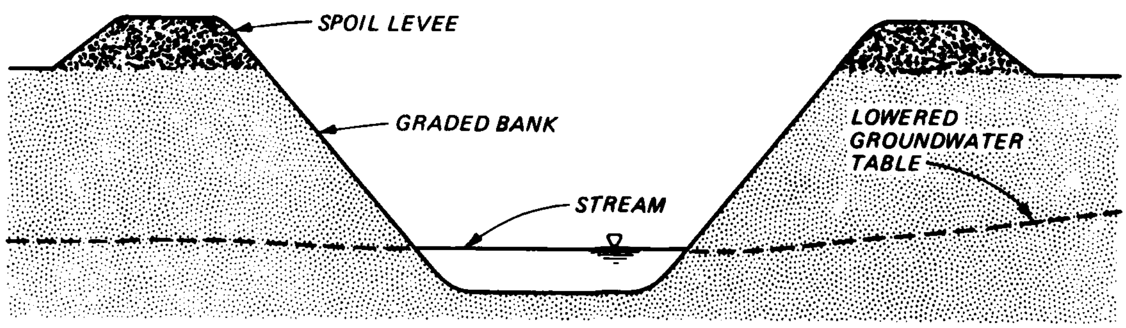
Figure 13. Stream channel enlargement using dredge (Use of dredge instead of land-based equipment minimizes clearing for access and disposal areas; photo courtesy of U. S. Army Engineer District, Vicksburg.)

sometimes swifter in modified channels, while low flows may be shallower and of longer duration. Although catastrophic high and low flows may decimate populations in natural streams, these catastrophic events are less frequent in an unaltered channel and recolonization occurs more quickly. Low flows in enlarged channels may be too shallow to support fish, or the stream may be one long riffle with no pools. Rooted vegetation may invade the channel at low flows, eventually creating a need for channel maintenance (McCall and Knox 1978, Linder 1976). Shallow depths are generally less valuable for recreation.

98. Channel enlargement also changes the hydrologic interrelationships between the stream, the floodplain, and the groundwater table. These interrelationships are illustrated by Figure 14. Although the




a. Unaltered stream




b. Enlarged stream channel with continuous levees built with excavated material

Figure 14. Impact of channel modification on hydrologic interrelationships (after Darnell et al. (1976))

practice of using excavated material from channel enlargement to build levees increases channel capacity, it reduces the stream-floodplain interrelationship. The levees may also erode and contribute sediment to the stream.

99. Dredged or excavated material may be placed in continuous levees as a management tool in some areas. Continuous levees made of dredged or excavated material have been used along canals and enlarged channels in marshy areas to maintain flow in adjacent streams (Scott 1972). Continuous banks of excavated material have been used in channelization work in Louisiana to prevent saltwater intrusion into a brackish coastal marsh. The banks are broken at points of confluence with tributaries. The same technique has also been applied in Louisiana to prevent drainage of freshwater wetlands adjacent to a channelized reach.*

100. Floodplain plant communities are adapted to flood frequency of the adjacent stream. Changes in floodplain plant population structure can be expected when the flood frequency is reduced by upstream reservoirs (Johnson, Burgess, and Keammerer 1976) or channel modification, or when flood regimes are changed by levees (Fredrickson 1979) or by channel aggradation due to poor watershed soil conservation. Overbank flooding allows nutrient-rich sediment to be deposited on the floodplain instead of transported downstream. Thus, changes in hydrologic relationships due to channel enlargement or alignment can affect downstream water quality (Rosendahl 1976).

101. Overbank flows are a source of groundwater recharge. The groundwater table may be lowered by increases in channel depth, which in turn results in changes in the overlying plant community. The increased groundwater flow into the channel will affect water quality and hydrology (Winner and Simmons 1977).

102. Winner and Simmons (1977) discuss the potential effects of enlarging a channel in a North Carolina swamp watershed on hydrology and water quality. They predicted that peak flows and base flows would

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* Personal communication, Mr. Virden Bordelon, U. S. Army Engineer District, New Orleans, 25 July 1980, and Mr. Paul Yakupcack, U. S. Fish and Wildlife Service, Latayette, La., same date.

increase and medium range flows would decrease. Groundwater level fluctuation would increase. There would be an increase in surface water dissolved solids concentrations, particularly at low flow, reflecting the increased groundwater contribution.

103. Environmental considerations for planning and design of channel enlargement should include a study of the hydraulics, biology and aesthetic value of the original stream. Consideration should be given to reproducing or improving the habitat diversity of the existing stream or preserving a part of the natural stream by using floodways or single bank modification, discussed in greater detail in paragraphs 172 through 183 below. The designer should consider the environmental consequences of (not necessarily in this order) the following:

a. Placement of excavated or dredged material.

b. Cross-sectional shape and uniformity.

c. Changes in substrate and substrate diversity.

d. Removal of channel armor.

e. High and low flow depths and velocities in the modified channel.

f. Increased peak flows downstream.

g. Changes in stream-floodplain-groundwater interactions.

Channel alignment

104. Channel alignment is often performed in conjunction with clearing and enlargement, particularly on small streams. Most of the environmental considerations associated with clearing and snagging and enlargement also apply here; however, only nonredundant material will be presented. The major environmental problems unique to channel alignment arise due to increased channel slopes and cutoff meanders.

105. Channel alignment usually increases the slope of the channel since the length is shortened. Increasing the slope will affect channel stability, since the slope is closely related to other morphologic variables. Improperly designed channels sometimes become extremely unstable and the stream erodes its banks and bed, damaging or destroying bridges (Figure 15) and washing away farmland (Linder 1976).

106. In addition to structural problems, channel instability is

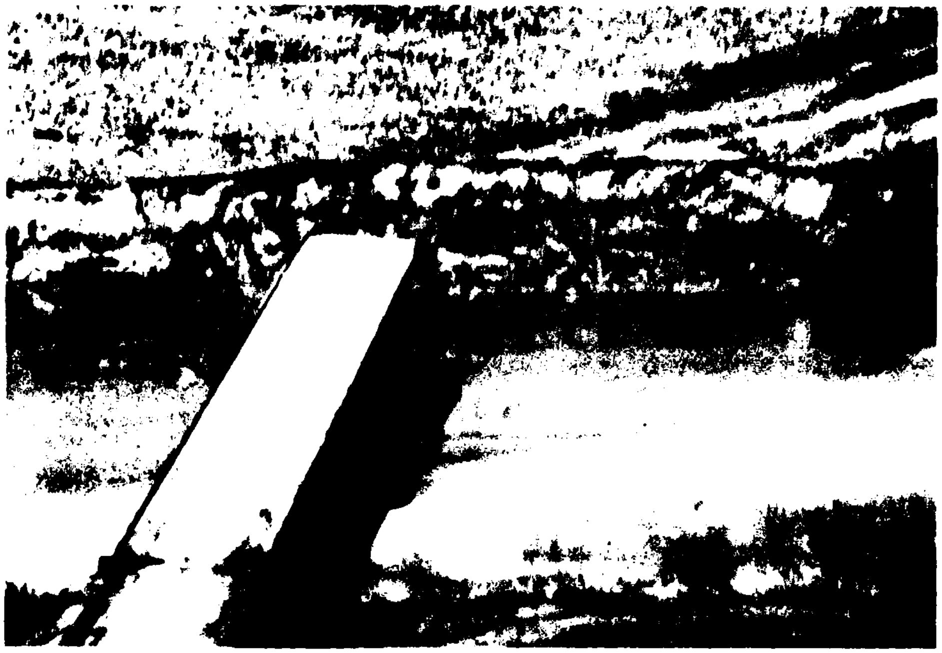

Figure 15. Bridge crossing destroyed by unstable channel widening (The site shown here is upstream of a channelized reach of Twenty-Mile Creek, Miss.; photo courtesy of the U. S. Army Engineer District, Mobile.)

usually accompanied by prolonged increased sediment loads and turbidity levels, which are detrimental to aquatic organisms. Sediment may smother some macroinvertebrates and clog the feeding apparatus of others. Unstable, shifting substrates are not conducive to macroinvertebrate production. Fish are indirectly impacted by loss of food resources, and some species are directly impacted by reduced visibility that interferes with feeding habits. Increased turbidity, which accompanies increased sediment loads, reduces photosynthesis by reducing light penetration. Turbid waters absorb more solar energy than clear waters and thus tend to be warmer.

107. A major environmental problem associated with channel alignment is the loss of aquatic habitat. Cutoff meanders can provide valuable backwater habitat to the riverine system if they are not filled in or dewatered. Typically a cutoff meander will be isolated from the main channel by sediment deposition at the points of confluence with the main

channel (Figure 7). The oxbow lake thus formed will eventually fill with sediment and become a terrestrial habitat. If the stream has been stabilized as well as realigned, new meanders will not form to replace those that are lost, as they do in unaltered fluvial systems. Realignment and stabilization of meandering reaches into straighter reaches thus leads to a reduction in the areal extent of aquatic habitat.

108. The loss of aquatic habitat due to channel alignment is a problem of serious magnitude. Bulkley et al. (1976) studied aerial photographs of Iowa streams and estimated that 1000-3000 miles of streams large enough to support year-round fish populations had been lost due to channel modification. Alignment of a 19-mile portion of the St. Francis River in Missouri resulted in a 57-percent decrease in active channel length (Fredrickson 1979).

109. A limited amount of field data is available from cutoff meanders, as summarized below:

a. Shipp and Hemphill (1974) studied two six-year-old cutoff meanders and three unaffected meanders on the Alabama River, a navigable stream. These cutoff meanders were young enough that the ends had not been plugged, and current velocity in the cutoff meanders was 30 to 50 percent of the unaffected meanders. Brush, logs and other cover were more plentiful in the cutoff meanders. Gamefish were more plentiful in the cutoffs and they provided better fishing spots since there was more structure (brush) and less boat traffic. Sandy point bars, which for some reason were gathering places for fish in unaffected meanders, were absent in cutoff meanders. Shipp and Hemphill recommended maintenance of significant flow in cutoff meanders since changes in cutoff habitat were related to changes in current.

b. The isolation and stagnation of the oxbow lake may give rise to anaerobic conditions. Cutoff meanders on the Kaskaskia River were blocked at the upper end in order to maintain adequate flows in the navigation channel. Anaerobic conditions were observed 3-6 ft below the surface as early as May and persisted until destratification.*

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* Personal communication, Dr. Edward Herricks, University of Illinois at Urbana-Champaign.

c. Bulkley et al. (1976) sampled two oxbow lakes that had been created by modification of small Iowa streams for highway bridges. The oxbows contained fewer species and numbers of fish than the main channel. Deep mud deposits in the oxbows indicated that they were becoming shallower. Two other cutoff meanders in the study area dried up completely during part of the sampling period.

d. Fredrickson (1979) observed rapid accumulation of sediments in cutoff meanders created by modification of the St. Francis River in Missouri. In some cases, the cutoff meander was deliberately filled and farmed.

110. A natural, meandering channel provides a diversity of depths, light conditions, substrates, and current velocities. Channel realignment frequently replaces meanders with relatively straight reaches of uniform cross-section, thus reducing aquatic habitat diversity. Large-scale reduction in aquatic habitat diversity may have significant long-term effects on the riverine ecosystem. Studies on the Missouri (Morris et al. 1968) and Lower Mississippi Rivers (Mathis et al. 1981) indicate that backwater areas such as sloughs, chutes, and oxbow lakes are valuable habitat for benthic macroinvertebrates in the river system. A decline in the acreage of these valuable areas could affect the production and diversity of some species of invertebrates and the fish that feed on them.

111. Although much is unknown about the physical and biological changes which occur in cutoff meanders, most published information credits the decline of cutoff areas to isolation from the main channel. Anderson (1974) details the difficulty of maintaining flows in cutoff meanders to avoid complete filling with sediment. A culvertlike structure at the upstream end may be used to supply flows, but unless a hydrostatic head exists across the culvert there will be little if any movement of water through the cutoff meander. If too much water is diverted through the cutoff meander, the river may attempt to revert to the old channel. The best situation is when the cutoff meander is supplied with enough flow from tributaries to prevent complete filling with sediment. Based on a physical model study of a reach of the Red River, Foster, O'Dell, and Franco (1982) recommended closure of the upstream ends of severed

bends to bank elevation and construction of structures at the downstream end to block movement of sediment-laden bottom currents as discussed later in the report.

112. Environmental considerations for channel designs that involve alignment include estimation and evaluation of the losses of aquatic and riparian habitat due to the eventual loss of cutoff areas. Consideration should be given to provisions for the maintenance of flow through cutoff meanders that are valuable from an environmental or recreational standpoint. The effect of alignment on channel stability is of prime importance and should be evaluated as the overall design is evaluated for stability. Consideration should be given to the effect of channel alignment on habitat diversity and aesthetics.

113. Channel alignment is frequently combined with clearing and snagging and enlargement to increase the flow capacity of natural channels. The environmental impacts of these actions are frequently combined, as shown in Figure 16. Biological impacts can usually be attributed to physical impacts.

### Channel lining and grade-control structures

114. Environmental considerations associated with design and construction of streambank protection projects are discussed in Part V of this report. Channel lining and grade-control structures are treated below.

115. Very few available studies present environmental data from lined or paved channels. Arthur D. Little, Inc. (1973) describes a channel project with a 5000-ft lined section through an urban area. No aquatic life was found in the lined channel. Perhaps the most extensive study of lined channels currently available is a study of the streams of Hawaii sponsored by the U. S. Fish and Wildlife Service (Parrish et al. 1978). After a survey of all Hawaiian streams and intensive monitoring of three watersheds, Parrish et al. found channel lining to be the most ecologically damaging type of alteration. Channel lining was found to promote water quality degradation, scenic degradation, and the replacement of native fish species by less valuable exotics.

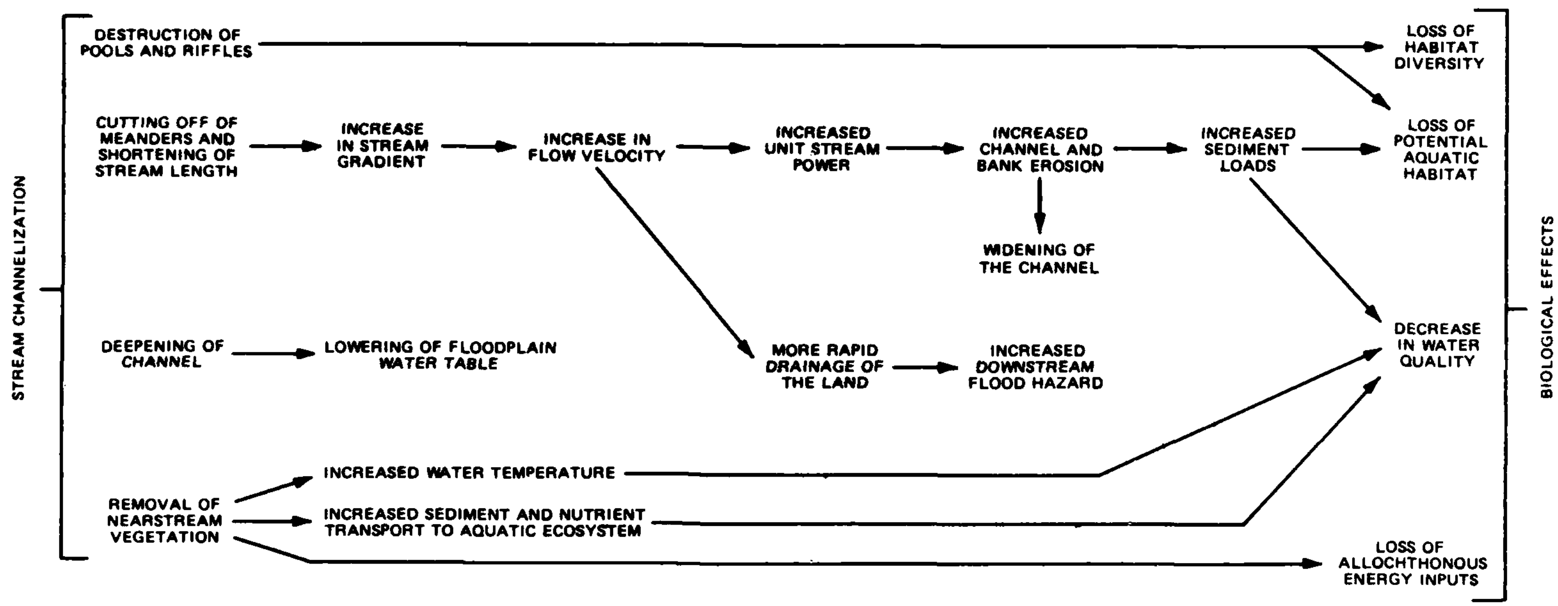


Figure 16. Combined physical impacts of clearing and snagging, channel enlargement, and alignment (after Darnell et al. (1976) from Karr and Schlosser (1978); copyright 1978 by the American Association for the Advancement of Science)

116. Water quality degradation in the lined Hawaiian channels was evidenced by excessively high values for pH (10 units) and temperature (36°C). Wide diurnal variations in these parameters and in dissolved oxygen content were observed. Figure 17 shows the temperature pattern in a lined channel compared to similar data for a natural stream. Excessive heating was caused by the lack of shade over modified channels, shallow water depths, focusing of solar radiation by vertical walls, and high heat transfer in concrete. Temperatures above lethal limits for native species were recorded in several lined channels (Hathaway 1978). The lined channels created conditions resulting in intense algal growth, and the photosynthetic activity of these growths caused strong diurnal fluctuations in pH and dissolved oxygen content (Norton, Timbol, and Parrish 1978).

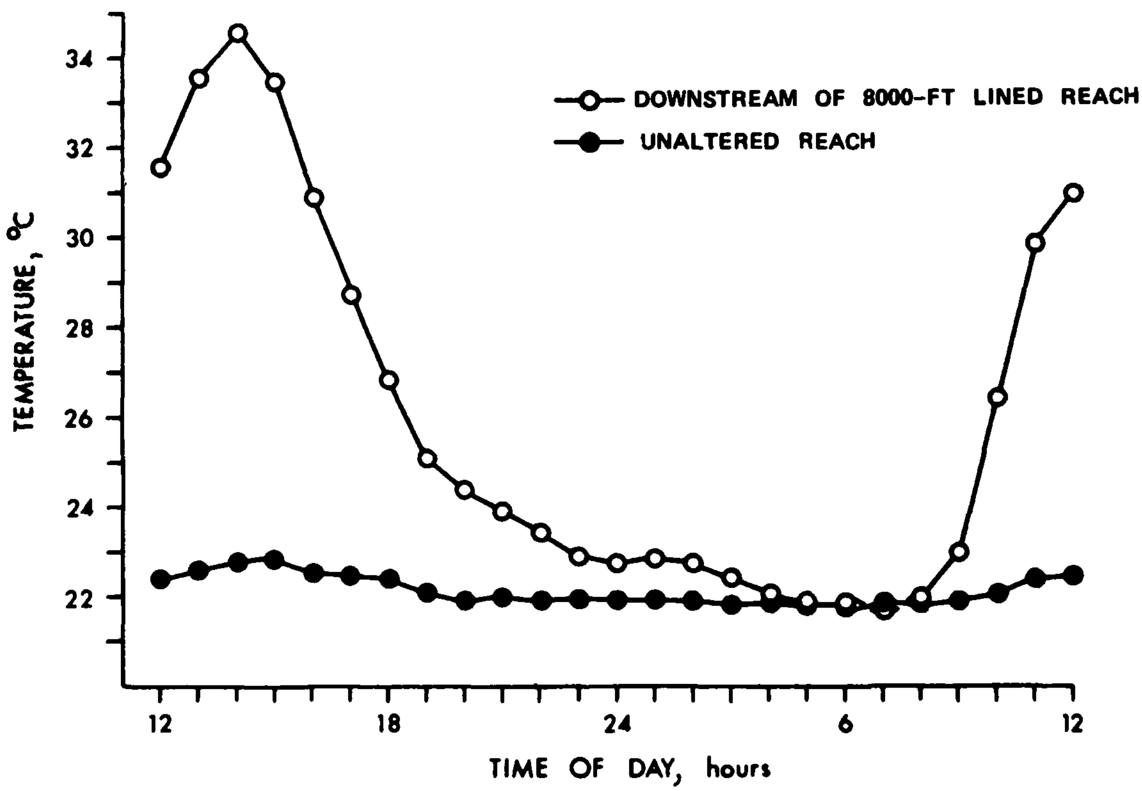


Figure 17. Impact of channel lining on water temperature; daily cycle of water temperature, Palolo Stream, Hawaii (from Hathaway (1978))

117. In addition to water quality degradation, native fish species were probably affected by the wide, shallow flows through lined sections and culverts that formed unnatural habitats and migratory barriers. The total loss of natural substrate was especially detrimental to native fish, most of which are bottom dwellers. Hardy exotics were observed to be rapidly replacing native species (Parrish et al. 1978). The increased velocities in lined channels may also be detrimental to aquatic organisms (Arthur D. Little, Inc. 1973).

118. Design of lined channels should include consideration of the impact the channel will have on the hydraulics and temperature regime of the natural stream. The magnitude of some adverse environmental impacts may be directly related to the length of the lined reach. Measures to minimize adverse impacts include the use of low-flow notches, preservation and replacement of riparian vegetation, and the use of boulder concrete for channel bottoms. In a stream that normally flows over a boulder-strewn bed, a bottom lining made of boulders protruding from concrete more nearly approaches natural conditions than plain reinforced concrete (Figure 1) (U. S. Army Engineer District, Honolulu 1975). No quantitative information is available on the relative impacts of various types of lining, however. Some transfer of information from studies of various types of bank protection might be possible.

119. Although grade-control structures and culverts are fairly common in modified channels, very little information is available on their environmental impact. Grade-control structures do have aesthetic impact which is related to their size and the conflict or harmony of their appearance with their surroundings. Grade-control structures usually provide some aeration to the stream. On the other hand, they may serve as barriers to the movement of fish and other aquatic organisms at low flows.

120. Culverts and grade-control structures made of closed conduits may have similar environmental effects. Most culverts replace natural substrate with artificial, greatly reduce illumination, and some have extremely steep gradients and shallow depths. Generally the culvert itself is an unsuitable habitat due to unnatural substrate and reduced

illumination. The significance of these problems is related to culvert length. If the downstream end of the culvert or grade-control structure is sufficiently elevated, fish movement may be blocked (Parrish et al. 1978).

121. McClellan (1970) made field evaluations of the fish passage capability of 66 highway culvert installations in Oregon. Several types of culvert were included in the survey, including a structural plate arch with an open bottom (Figure 18). This type of installation most nearly approaches a bridged crossing and creates a natural type of substrate and bed slope. Depths suitable for fish passage in culverts may be provided by installing baffles made of concrete or treated wood or by limiting culvert invert gradient to a maximum of 5 percent and culvert length to a maximum of 50 ft. Properly designed baffles did not cause maintenance problems in the installations inspected. Culvert design may preclude fish passage for 24-48 hours during peak flows without adverse effects. Conditions at the ends of the culverts sometimes hindered ingress and egress, although the culvert itself was passable. The controlling parameters for fish passage through culverts are water velocity through the culvert, length of the culvert, and species of fish using the stream.

## Existing Guidelines

122. Existing environmental guidance for designing and constructing channel modifications is scarce and largely qualitative. Environmental recommendations are usually based on intuitive approaches to habitat preservation or restoration. The hydraulic characteristics of environmental features are virtually never discussed in the literature. The status quo of design guidance reflects the lack of information available on the functions and interrelationships of various components of stream ecosystems. Such basic research is needed for improved designs (Karr and Schlosser 1978). Existing design guidance is more akin to general policy than detailed design guidance. Specific methodologies for implementing the general guidelines are yet to be developed and documented.

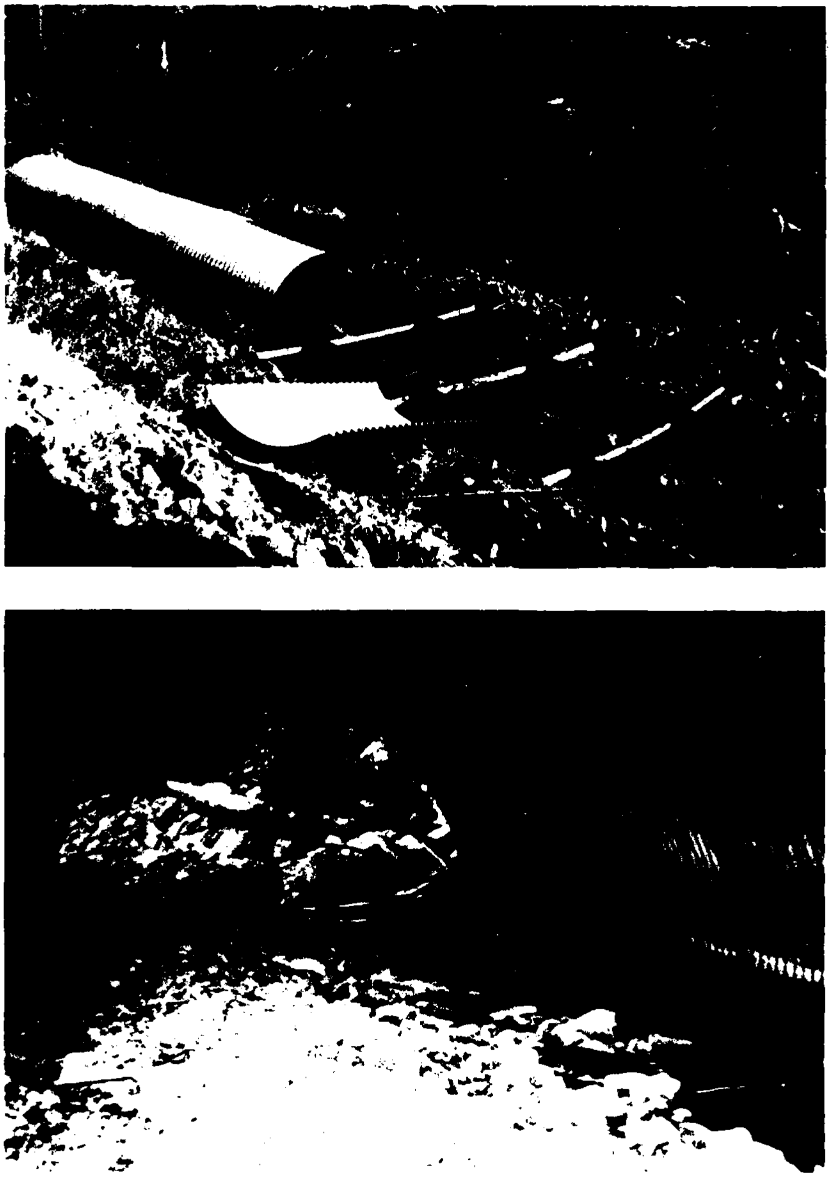

Figure 18. Open bottom arch culvert (Structural plate arch culvert reduces adverse impacts on fish by maintaining natural grade and substrate; photo courtesy of the Federal Highway Administration.)

## SCS guidance

123. The SCS manual "Design of Open Channels" (U. S. Dept. of Agriculture Soil Conservation Service 1977) contains a chapter published in 1971 entitled "Environmental Considerations in Channel Design, Installation, and Maintenance." This work is summarized in an EPA report (U. S. Environmental Protection Agency 1973). Information is presented on stream characteristics which lend themselves to the development of wildlife resources, fish resources, and recreation. Water quality criteria and stream channel characteristics conducive to the development of natural fisheries are treated briefly. Criteria governing the usefulness of a stream for various types of recreation (fishing, hunting, swimming, boating and canoeing, hiking, etc.) are presented. Simple procedures are presented for evaluating the resource potential of the undisturbed stream.

124. The SCS manual encourages design practices which protect and enhance stream resources. In particular, the use of existing channel alignment is encouraged, with floodways to carry high flows. Uniform channel geometry is discouraged. Designs are to "take advantage of local variations of in-bank stability and capacity." Natural cross-sectional shapes--steep slopes on the outside of bends and gradual slopes on the inside of bends--should be duplicated wherever possible. Placement of excavated or dredged material is to be as unobtrusive as possible, and clearing should be held to a minimum. Improved public access can be developed to enhance the use of stream resources.

125. The restoration of stream and riparian habitats is also discussed by the SCS manual. Conceptual drawings illustrate the use of felled trees, rocks, and man-made structure to provide cover and shelter for fish (Figure 19). A guide for selection of vegetation to be replanted on excavated material and cleared areas is given. Projected uses of these areas (recreation and wildlife) determine the plant species to be used.

126. SCS design guidance is general and adapted to the specific needs of that agency. Revision of the environmental design guidelines by the SCS to incorporate the experience gained over the last 10 years

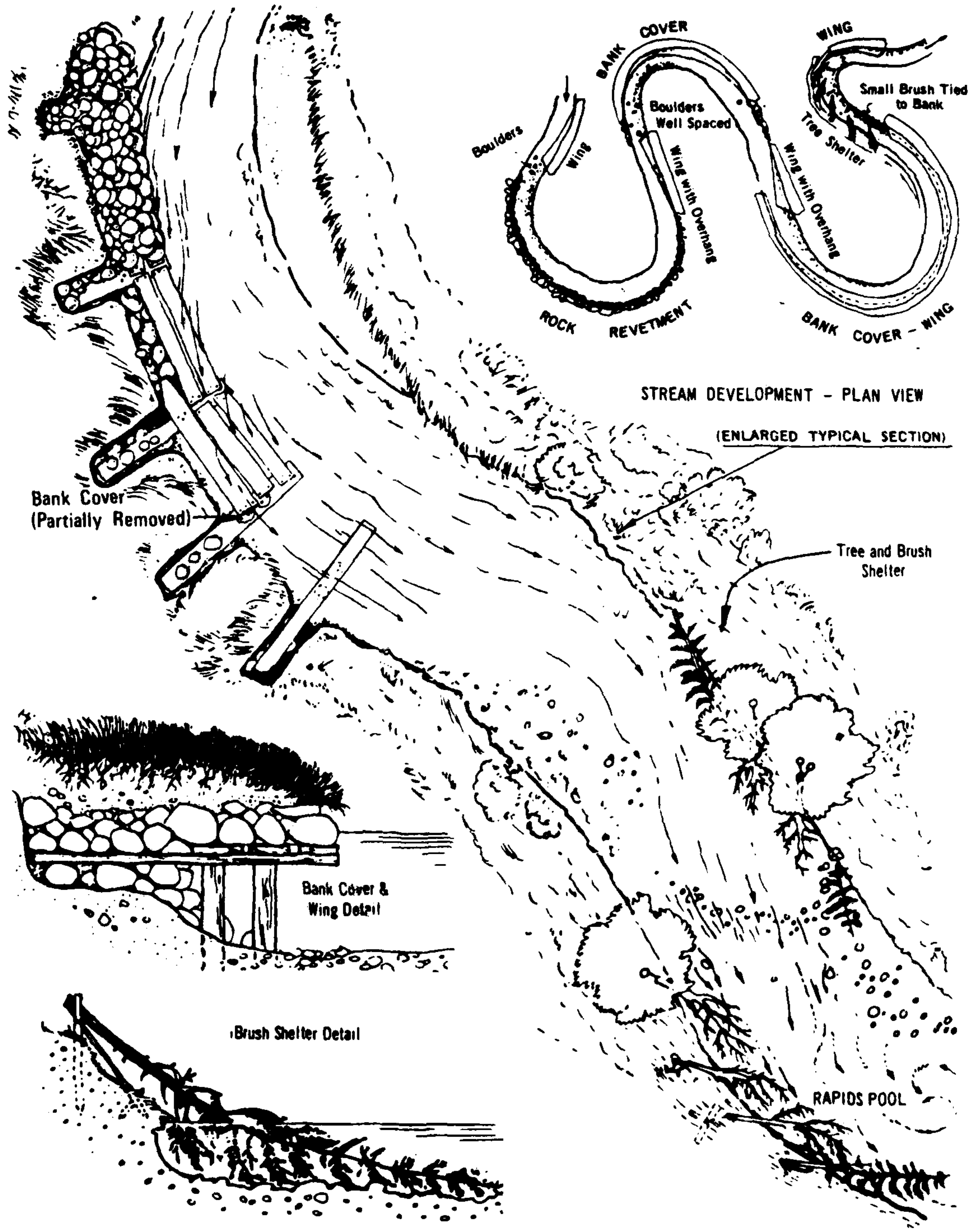


Figure 19. Fish habitat development (from U. S. Dept. of Agriculture Soil Conservation Service (1977))

would undoubtedly result in more specific and quantitative guidance.

SCS-FWS joint guidelines

127. In 1978 the SCS and the U. S. Fish and Wildlife Service (FWS) jointly published guidelines for channel modifications (General Services Administration 1978). These guidelines deal with planning and consideration of alternatives as well as design and construction of channels. They are generally more policy-oriented than technical.

128. The joint guidelines prohibit consideration of channel modifications that jeopardize endangered or threatened species, result in restricted access to public use areas, or that intentionally or unintentionally will result in drainage of certain types of wetlands. Additional restrictions deal with scenic rivers, wilderness areas, and "important habitat values."

129. The joint guidelines specify that a full range of both structural and nonstructural alternatives to channel modification must be considered. Channel modification is not to be considered if a practical alternative exists; it is therefore a last resort.

130. The joint guidelines limit channel modification to the "minimum required, either alone or in combination with other measures." The use of least damaging construction techniques and equipment is required in order to preserve as much of the existing channel characteristics and riparian habitat as possible. The following construction practices are mentioned but not required:

- a. Seasonal construction.
- b. Minimum clearing.
- c. Reshaping excavated material.
- d. Limiting excavation to one bank (on alternating sides where appropriate).
- e. Prompt revegetation of disturbed areas.

State policies

131. Some state wildlife agencies have adopted policy statements on channel modification or statements on wetlands which explicitly mention channel modification. These statements typically focus on modification of streams not open to commercial navigation for flood control

and drainage. A complete survey of all states was not possible within the time frame of this study, but a summary of the policy statement presented by the North Carolina Wildlife Resources Commission is found below.

132. The North Carolina Wildlife Resources Commission (1976) published a strong statement of policy on stream channelization. Their guidelines for channel modification are early work in this field, and reflect a stated philosophy on the environmental values of streams, wetlands, and floodplain land use. As such, they leave little flexibility for the exceptional case. Once again, these guidelines are general and are not detailed engineering guidance. Channel stability is treated in an oversimplified fashion.

133. The North Carolina policy calls for restricted floodplain use, maintenance of stream channels to keep them clear of felled trees and other obstructions, and increased emphasis on land use practices which promote infiltration instead of runoff. Channel modification is not to be done to protect lands affected by annual (or more frequent) floods. Channel modifications which are done primarily to enhance land drainage are prohibited, and channel enlargement is limited to restoring the original flow capacity of the stream. That is, stream channel enlargement should be limited to the removal of "man-made wastes or the results of natural catastrophes."

134. The North Carolina policy identifies the following environmentally sensitive design and construction techniques:

- a. Channels should not be realigned. The modified channel should be in the original stream channel "with all of its meanders, pools, and riffle reaches."
- b. Enlargement should be limited to channel deepening with no increase in width allowed. This restriction is called for to maintain sufficient depths for fish, keep the channel free of silt and eliminate maintenance, and to maintain cooler stream temperatures.
- c. Rights-of-way for equipment should be on the north or west side of the streambed and as narrow as possible, preferably less than 50 ft.

d. Excavated or dredged material should not be piled in levees or berms, but should be spread out to allow rapid revegetation by native species.

### Corps guidance

135. There is no existing CE design guidance for channel modifications that contains detailed information on environmental considerations. No existing guidance effectively integrates hydraulic design and environmental considerations.

## Improved Channel Modification Designs

136. Despite the absence of formal environmental criteria for channel design, considerable innovation has taken place. Improved design, construction, and maintenance practices may be gleaned from the literature and from interviews with professionals in the field. An exhaustive survey of all projects incorporating innovative environmental protection measures is beyond the scope of this report. Future research, however, should include a systematic survey of agencies involved in channel modification to identify and document improved designs. Improved design, construction, and maintenance methods may be categorized as follows:

a. Restoration of an earlier, greater flow capacity by selective clearing and snagging, limited sediment removal, and bank stabilization.

b. Use of artificial structure to create aquatic habitat.

c. Modified cross sections, including single bank modification, low-flow notches, fish berms, composite channels, floodways and levees.

d. Management of cutoff meanders.

Some projects have incorporated environmental features using the previously mentioned guidelines, while other environmental features have resulted from innovation by individual design teams.

### Restoration of flow capacity

137. Stream restoration or reclamation, as it is sometimes called, is the process of increasing the flow capacity of either a modified or

unaltered channel to an earlier, higher level by removing log jams and other obstructions and, in some cases, sediment deposits. "Restoration" as used here does not necessarily imply a restoration of habitat or of floral and faunal populations.

138. Restoration differs from more traditional channel maintenance in several ways. An emphasis is placed on preserving riparian vegetation by using manual labor and small heavy equipment. Clearing and snagging specifications may be written in greater detail to include controlled access; types of equipment to be used; the method of debris disposal to be used; and sizes, locations, and popular names of trees to be left. Specific trees to be preserved may be marked prior to the start of work. Work typically follows existing channel alignment, and costs are typically much lower than for traditional modification.

139. Restoration work as presently practiced is more art than science; the technique is of a skilled, intuitive nature. Restoration requires skills which are not presently available in many localities. Commercial contractors must be trained and closely supervised when using this method.

140. Further limitations on restoration include limited application, maintenance requirements, and limited results. Restoration of channel flow capacity cannot increase the flow capacity of the stream above its "original" level. Its application is limited to projects with favorable objectives, topography, soils, land cover, and rainfall patterns. Restoration is not generally suitable for projects with drainage objectives. Documented experience with the restoration concept is presently limited to a few streams of the Eastern United States. Streams which have been restored by selective removal of snags and obstructions have to be checked at least annually to ensure that channels are kept clear.

Briar Creek restoration project

141. Nunnally and Keller (1979) describe design, construction, and performance of a project that restored the flow capacity of a small urban stream. Briar Creek, with a drainage area of approximately 10 square miles, was modified to convey a design flow of 1500 cfs (return period of two years). The modified channel is expected to lower the maximum

stage of the 20-year flood event by 2 ft. Stream channel stability as measured by a U. S. Forest Service rating system was improved by restoration. Biological effects of the project were not evaluated. Details of design and construction are summarized below.

142. Sizing. Cross-sectional area for the modified channel was determined by:

a. Measuring the existing cross-sectional area.

b. Computing a design cross-sectional area using relationships between drainage area, land use, and channel geometry from Dunne and Leopold (1978). An alternate approach for urban basins from Hammer (1971, 1972) was also presented. These relationships are empirical and were developed with limited data, so it might be useful to develop similar relationships for the area of interest.

c. The larger area from the above two methods was used. The larger of the two turned out to be the existing cross-sectional area.

143. Shaping. A procedure for computing channel dimensions for compact trapezoidal channels developed by the U. S. Bureau of Reclamation was used. The formulas are:

$$d = 0.5\sqrt{A}$$

$$b = (4 - z)d$$

where

$d$ = mean depth

$A$ = cross-sectional area

$b$ = mean width

$z$ = side slope

Side slope was chosen to be 1V on 2H. Larger widths were necessary in curved reaches and the slope of inside banks was increased to 1V on 3H to approximate natural cross-sections. In curved reaches the increase in width was reduced by the use of riprap on the outside banks.

144. The net effect of the above sizing and shaping procedure was to change the overall geometry of Briar Creek very little. Most excavation involved the reshaping of banks to more gradual slopes. The existing channel alignment was followed.

145. Bank stabilization. Bank stabilization was aided by the choice of side slopes which were less than the angle of repose. Trees which were not in the channel or in danger of falling into the channel were carefully preserved by limiting equipment access and using manual labor as much as possible. Stable banks protected by root wads were not disturbed even to shape the banks to the design slope. Riprap was carefully sized using the method of Maynord (1978) and was placed sparingly at points of expected maximum shear. Diagrams from Varshney and Ramchandra (1974) and Leliavsky (1955) were used to estimate the location and extent of zones of unacceptable shear. Additional riprap was placed after visual inspection of the channel following high flows. SCS guidelines were used for vegetative stabilization of banks and disturbed areas.*

146. Construction. Construction of the Briar Creek project was labor intensive and carefully supervised. First, brush and trash small enough to handle with hand tools were removed from the channel by laborers. Heavy equipment (hydraulic hoes or backhoes) were then used to remove larger trees and debris and to pull slopes back to the design slope. Banks already stabilized by tree roots were not disturbed. Excavated material was spread out in low spots to improve local drainage. Finally, riprap was placed and disturbed areas were mulched and seeded.

147. Maintenance. After the modified channel was subjected to high flows, visual inspections were made. Additional riprap was placed where needed and bare spots were reseeded. Periodic maintenance is required to remove vegetation and brush from the channel.

## IWR Study

148. George Palmiter, an amateur conservationist from Ohio, has applied restoration practices similar to those described by Nunnally and Keller to several streams (East 1977). Palmiter's work has been on streams large enough for canoeing--considerably larger than Briar Creek. Palmiter's methods could be characterized as selective clearing and

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* Darnell et al. (1976) voice opposition to the use of exotic species for stabilization of construction areas.

snagging and bank stabilization using vegetation or brush. Since the nature of his work is skilled and intuitive and has never been documented or evaluated in professional terms, the U. S. Army Engineer Institute for Water Resources (IWR) has funded a study by the University of Miami, Ohio, to quantify the methodology and effectiveness of Palmiter's work.

149. Brief descriptions of Palmiter's methods are found in East (1977) and in the research proposal submitted to IWR by Willeke.* Log jams or debris in the stream channel that interfere with flow are cut by hand and are floated into place to protect the outside of bends or unstable banks (Figure 20). Leaning trees in danger of falling into the

Figure 20. Repositioning snags (Fallen trees may be repositioned parallel to the flow to protect eroding banks; photo courtesy of C. A. McConnell and the Soil Conservation Society of America.)

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* Willeke, G. E. 1979. "An Evaluation of River Restoration Techniques in Northwestern Ohio," Proposal submitted to the U. S. Army Engineer Institute for Water Resources, Fort Belvoir, Va., 16 pp.

stream are trimmed or topped, but the root structure is left intact. Sediment is moved by placing logs and branches to divert flow toward sediment deposits. Older trees are selectively cut to encourage thick stands of young trees to stabilize banks. Shade over the stream is preserved to prevent the establishment of rooted aquatic plants. The stream must be inspected annually and minor adjustments made to remove newly fallen trees and to correct any situations causing excessive flow retardance or erosion.

150. Part of the Wolf River in Tennessee was modified using restoration techniques (McConnell et al. 1980). The guidelines for this project used are reproduced in Appendix A. The Wolf River is 50 to 80 ft wide, and average flow in the work area is about 103 cfs. Twelve miles of the stream were modified using restoration techniques, and 22 miles using heavy equipment. The cost per mile for restored segments was roughly half the cost for the segments modified with heavy equipment. Laborers using small boats hooked cables to logs in the river to be pulled out by small crawler tractors (Figure 21). Debris and sediment were often flushed away as snags were removed. Heavy equipment was used sparingly in restored segments to remove sediment from channel sections which were almost completely blocked. Most segments modified with heavy equipment were worked from one bank. Restored segments were aesthetically pleasing (Figure 22), but probably suffered some loss of aquatic productivity and diversity due to the removal of instream habitat structure.

Artificial structure

151. Habitat diversity of natural or modified streams may be increased by placing structure in the channel. Randomly placed boulders, small check dams, artificial riffles, bank covers, and current deflectors are some of the structures which have been tested by various investigators (Figures 19 and 23). These methods, collectively referred to as "stream improvement" or "stream rehabilitation," have been employed with varying degrees of success by fishery managers for several decades. The basic principle involved in the use of artificial structure is the restoration of habitat and habitat diversity conducive to the growth and

a. Hand labor crew in a jon boat hooking cables to logs in river

b. Small crawler tractor winching the log out and dragging it clear of the floodway to prevent reentry into the channel during floods (Tractor is small enough to operate with minimal damage to the floodplain.)

Figure 21. Removal of snags using restoration techniques (photos courtesy of C. A. McConnell and the Soil Conservation Society of America)

Figure 22. Reach of Wolf River, Tenn., modified using restoration guidelines in Appendix A (photo courtesy of C. A. McConnell and the Soil Conservation Society of America)

a. Gabion wing deflector

b. Rock check dam

c. Randomly placed boulders

Figure 23. Stream improvement structures (from Barton and Winger (1973))

propagation of desirable species. Structures provide substrate diversity and cause scour holes to develop downstream.

152. A standard work on the use of artificial structure for habitat restoration is "Guidelines for Mangement of Trout Stream Habitat" by White and Byrnildson (1967). Much of this work deals specifically with development of trout habitat in the Wisconsin environment, but several general principles are stated which would apply to most stream habitats. Bank stabilization and the design, construction, and performance of several types of artificial structures are discussed. Major structures should be 5-7 stream widths apart to match the pool-riffle sequence of a natural stream. Slightly shorter pools may be best for trout. Triangular wing-deflectors (Figure 24) are used to deepen pools and create meanders. Sometimes banks opposite deflectors must be riprapped. Scour holes may be produced on extremely steep reaches by low barriers or dams made of logs or rocks (Figure 25). Bank covers are overhanging ledges which provide good habitat for larger trout (Figure 19). Less expensive, but quite effective forms of artificial structure include randomly placed boulders and submerged brush anchored to the bank (Figure 19).

153. Barton and Winger (1974) present a catalog of stream improvement structures and some general guidelines for their use. Although complete restoration of the communities of modified streams is usually impossible or impractical, skillful use of artificial structures can alleviate many of the undesirable effects of modification. Unwise use of structures can result in additional damage such as undercutting of banks or blockage of fish migration routes. Poorly designed structures may also be ineffective in producing aquatic habitat. It should be noted that stream improvement structures will have little effect on conditions caused by channel instability or poor soil conservation practices in the watershed.

154. Barton and Winger (1974) suggest that a study be made of existing and projected conditions in the stream before stream improvement is attempted. The purpose of the study should be to ascertain the type of habitat deficiencies that will exist for the desired aquatic community. As a general rule, the rehabilitated modified channel should

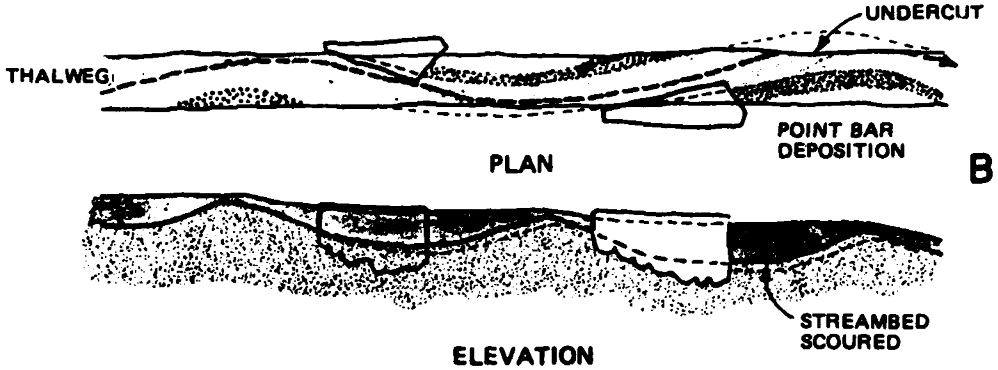



Figure 24. Wing deflectors (Wing deflectors may be added to a channel to increase sinuosity and to scour pools; rock revetment is usually needed on the bank that is opposite deflectors; after White and Byrnildson (1967))

Figure 25. Hewitt ramp (This log barrier made of securely anchored logs scours a pool at its downstream face; photo courtesy of the Minnesota Dept. of Natural Resources.)

have a similar percentage of shade, pools, and shelter as the natural channel prior to modification. Structures should be designed and constructed to withstand high flow conditions. The impact of the structures on sediment transport should also be considered.

155. Many types of stream improvement structures seem to have hydraulic effects that are opposed to the basic purposes of channel enlargement and alignment. The ideal structure would encourage pool formation at low flow, would not obstruct water movement at high flow, and would not be affected by sediment deposition. Rock structures provide good substrate for invertebrates, and structures that extend into the stream one-third or more of the channel width tend to produce the best scour holes. However, such structures may require protection of the opposite bank and the net effect will be a narrower, deeper channel (Witten and Bulkley 1975).

156. Nelson, Horak, and Olson (1978) present conceptual drawings and literature references for several artificial structures used at various locations in the Western United States. The use of such devices seems to be limited by cost and maintenance problems. The use of current deflectors, check dams, gabions, and large boulders is mentioned briefly. Flow deflectors are not recommended for use in streams that experience extreme fluctuations in flow or streams with gradients steeper than three percent. Randomly placed boulders work best in streams that have less than twenty percent of the surface area in pools.

### Field studies of streams with artificial structures

157. Barton and Winger (1973) discuss the use of gabions, loose riprap, concrete check dams, and randomly placed boulders as part of modification of the Weber River in Utah. Scour downstream of most structures produced vertical relief quite similar to that in the natural channel (Figure 26). Two to three years after modification, numbers, density, and diversity of macroinvertebrates and fish in the modified sections were the same as in the unchanged portions of the river. More fishermen used the modified sections due to ease of access.

158. Some 59 structures were installed in modified reaches

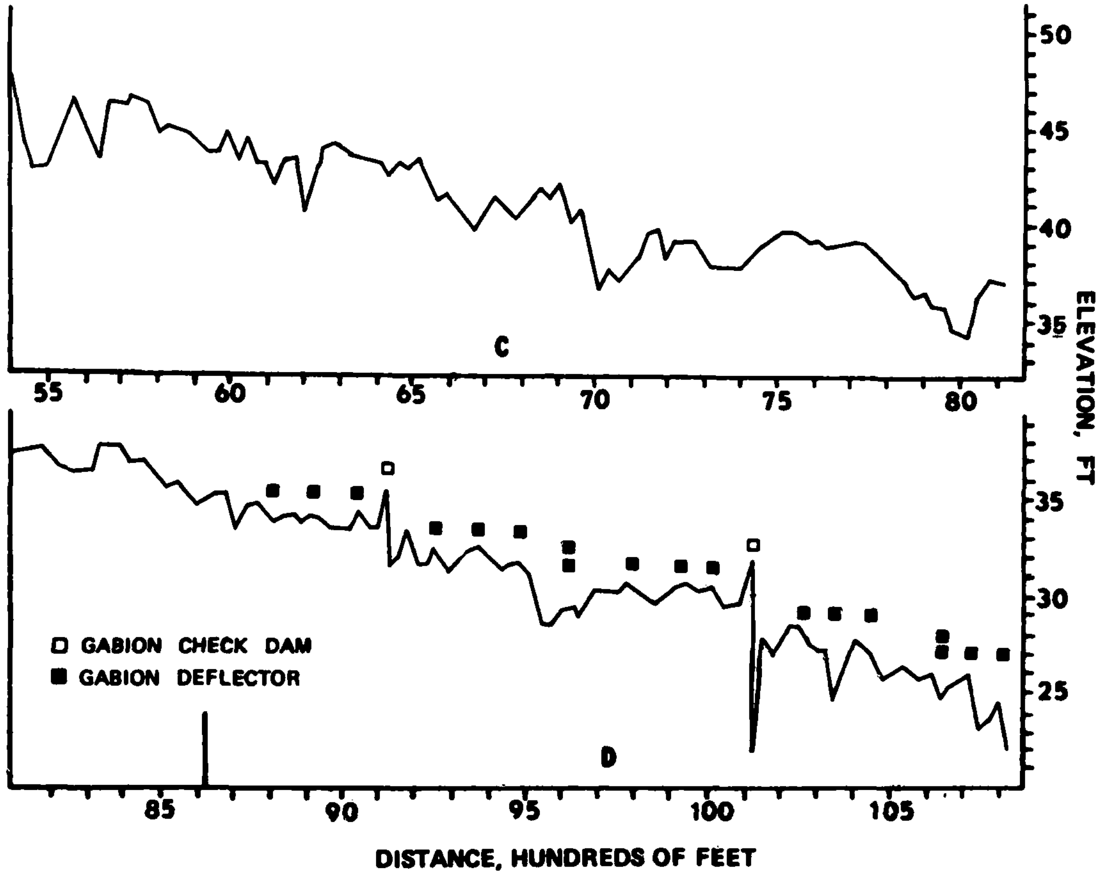



Figure 26. Effect of stream improvement structures on channel relief; longitudinal profiles for an unaltered natural reach and a modified reach with gabion wing deflectors and check dams, Weber River, Utah (from Barton and Winger (1973))

totaling 1.6 miles scattered along 7-8 miles of the river. Modifications were done in conjunction with highway construction. The modified channel was a trapezoid with a bottom width of 70 ft and side slopes of 1V on 1H.

159. Structures had little effect on the stage of high flows since no structure projected more than 1.5 ft above the normal water surface. Structures have generally performed well, although some of them were not effective in producing scour holes due to improper placement, and some of the gabion wire baskets have rusted and failed.*

* Personal communication, Dr. James R. Barton, Brigham Young University, Provo, Utah, 19 June 1980.

The successful performance of most of the structures both biologically and structurally was probably aided by flood control at an upstream reservoir. Although the design flow for the modified reaches was 5400 cfs, streamflow remained less than 1800 cfs during the study.

160. Winger et al. (1976) studied the effects of channel modifications and the use of stream improvement structures at an SCS project on Crow Creek, Tenn. and Ala. Stream improvement structures intalled on Crow Creek included riprap bank protection, paired deflectors, check dams, and sheet piling stabilizers. Some 11 stations were sampled over a 2-year period. Diversity and abundance of fish populations were found to be directly related to the diversity of habitat conditions. Stations featuring stable riffle-pool complexes had more diverse and abundant fish populations than stations which had mostly pool habitat.

161. Most of the stream improvement structures were effective in producing the desired riffle-pool sequence; however, some of the structures were built either too close together or with too high a crest elevation and ponded water over potential riffle areas. Riprap bank protection stabilized eroding banks and provided cover for game fish and stable substrate for epifaunal and benthic populations.

162. Griswold et al. (1978) studied five modified rivers in Ohio and Indiana. Artificial structures were tested on one river, the Olentangy of Ohio. Data were taken from a natural area (control), a site altered five years previously, and a site altered 25 years prior to the study over a three-year period. Five artificial riffle-pools were constructed in the reach which had been modified for five years. Physical data from the river and the three study sites are given in Table 2. Figure 27 shows the study areas.

163. The artificial riffles in the mitigated reach were each 20 ft long and were separated by pools 820 ft long. Riffles were constructed of boulders over earthen fill. Pools had a maximum depth of 8.2 ft at mean discharge. The deepest portions of the pools were excavated next to the steeper bank which was heavily riprapped. The opposite half of the river bed sloped gently upward to a 50-ft-wide grassed floodplain.

Table 2

Physical Characteristics of Study Sites on the Olentangy River, Ohio (after Griswold (1978))

| Study Site | Drainage Area square miles | Length miles | Minimum Flow cfs | Maximum Flow cfs | Average Flow cfs | Average Gradient ft/mile |
|---|---|---|---|---|---|---|
| Total | 537 | 88 | 8.5 | 16500 | 450 | 5.7 |

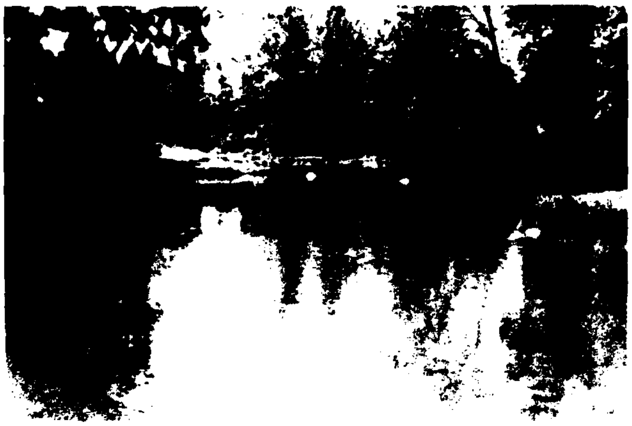
| | Average Width ft | Length of Reach ft | Mean Depth* ft | Maximum Depth* ft |
|---|---|---|---|---|
| Natural | 81 | 2937 | 2.7 | 6.0 |
| Mitigated | 117 | 4431 | 5.4 | 8.1 |
| Channelized | 165 | 2643 | 0.6 | 2.7 |

* During mean flow.

164. Analysis of fish and macroinvertebrate data from the three study sites revealed that the artificial riffle-pools were effective in improving the habitat of the modified stream. Macroinvertebrate production, standing crop, and relative abundance in the reach with artificial riffle-pools approximated that of the unaltered control area. Diversity of both macroinvertebrates and fish in the artificial riffle-pools was between diversity levels observed in the control and old channelized areas. The old channelized reach was constructed over 25 years prior to the study but had not recovered an aquatic community comparable to the other two study sites (Griswold et al. 1978). Effects of the mitigation structures on channel hydraulics were not discussed.

165. Griswold et al. (1978) recommend the use of artificial riffles and large rock riprap in all channel enlargement/alignment projects to provide substrate and habitat for desirable species of macroinvertebrates and fishes. Other recommendations include:

a. Deep pools should be available downstream from artificial riffles. Increases in width should be minimized in these areas to minimize sediment deposition.



a. Unaltered control area

b. Modified reach with series of artificial riffle-pools (5 years)

c. Old modified reach (25 years)

Figure 27. Use of stream improvement structure, Olentangy River, Ohio (photo courtesy of Ohio Cooperative Fishery Research Unit, U. S. Fish and Wildlife Service, Columbus, Ohio)

*b*. Public access should be provided to mitigated areas to ensure beneficial use of the resource.

*c*. Unaltered refuges are needed in case of drought. These may include unaltered receiving streams or tributaries. Occasional unaltered reaches should be preserved in channel projects that affect more than 35 miles of stream length.

*d*. Alteration of the bottom in natural streams should be minimized where possible.

166. Lund (1976) studied the morphology and gamefish populations of the St. Regis River of Montana (average flow 562 cfs, mean width 40 ft). Several reaches of the stream were modified for highway and railroad construction, and some reaches were provided with artificial structures--jetties and random rock clusters. No descriptions of these structures were given. Gamefish populations in altered sections with mitigation structures recovered from construction in about one year, while trout populations in some altered sections without mitigation had not recovered in 50 years.

167. The artificial structures were effective in producing stream bottom contours similar to those found in unaltered sections. Design details of the structures are not presented in the report. Some of the structures did fail during a flood. Channel stability was not a problem, probably due to the large, rocky bed material. No information is given on the effect of the structures on channel hydraulics.

168. Witten and Bulkley (1975) evaluated the potential usefulness of several types of bank stabilization structures as stream improvement structures. Data were taken from short channelized reaches of small Iowa streams modified for bridge construction. Since some of the bank protection structures around the bridge abutments protruded into the stream channel, they were similar to some of the stream improvement structures discussed above. Structures evaluated included riprap revetments, fences on or parallel to the bank, pile dikes, and stone dikes. Generally fences were used to stabilize low banks and dikes were used on high, steep banks.

169. The Iowa streams had heavy sediment loads and shifting substrates relative to the streams studied by Barton and Winger (1973) or

Lund (1976). Low head check dams installed to protect bridge pilings rapidly filled with sediment. Random rocks or boulders probably would have been ineffective since they would quickly scour holes large enough to bury themselves.

170. Fish and macroinvertebrate populations were sampled along structures and in upstream control reaches. Riprap revetments were found to provide better habitat for mayflies and caddisflies than control area substrates. Macroinvertebrates rapidly colonized rock dikes and revetments, but not steel structures. Neither size nor abundance of gamefish varied significantly between control areas and structure areas. However, one type of structure (pile dike) that protruded far enough into the channel to create downstream scour holes did increase the abundance of black bullheads.

171. McCall and Knox (1978) describe the use of single-bank modification, rock current deflectors, and leveling and planting excavated material in several Indiana stream modification projects. On one project, rock current deflectors had maintained pool depths of about 3.5 ft over a 5-year period, with a positive effect on fish species diversity. Eleven species of fish were found in the stream prior to construction, nine species during the year of construction, and eighteen species were found after construction. Previously uncollected species included smallmouth bass, green sided darter, silverjaw minnow, spotted bass, bluegill, and longear sunfish.

Modified cross sections

172. A wide range of innovative channel designs have used some form of modified cross section. Traditional design calls for a trapezoidal cross section with constant dimensions for each reach. The principle behind the use of most modified cross sections is to provide alternate channels for high and low flows. Low flows are confined to a small channel to avoid extremely wide, shallow flows and shoaling, and the high flow channel prevents excessive overbank flooding. Modified cross sections include the use of low-flow notches, floodways, levees, fish berms, and single-bank modifications. Fish berms and single-bank modification are measures designed to produce or preserve habitat diversity in the modified channel.

Low-flow notches

173. Low-flow notches are shallow channels excavated in the bottom of larger cross sections (Figure 28). Alternately, the original channel may be used as a low-flow notch within a floodway or between levees. Low-flow notches have been used sparingly for several years to improve the sediment transport characteristics of channels by preventing shoaling at low flows.

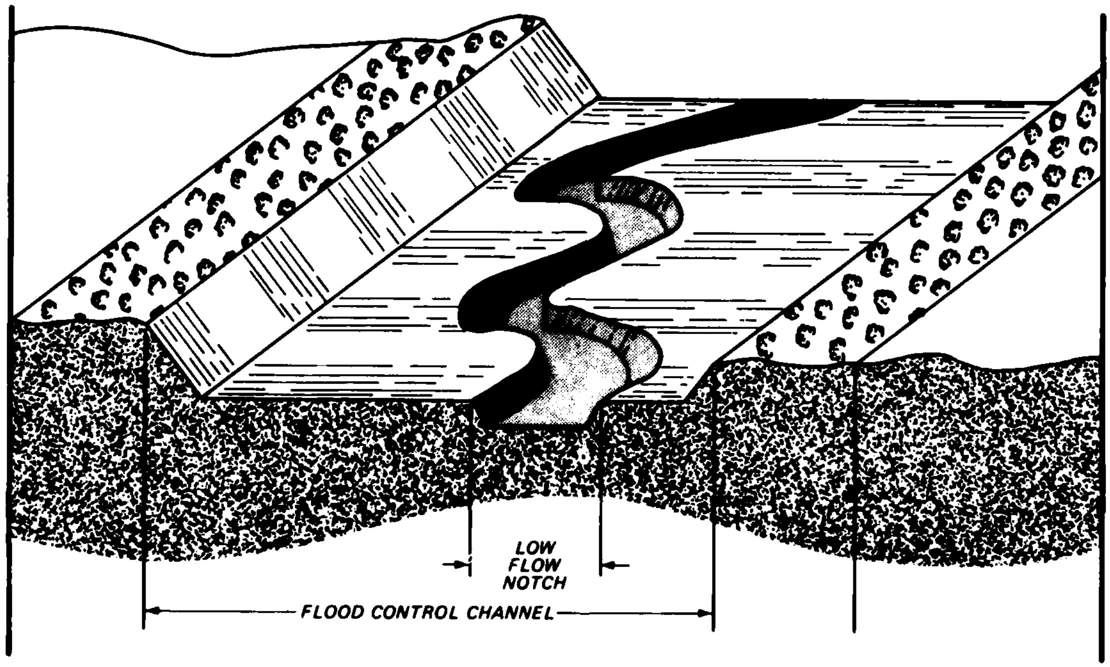



Figure 28. Low-flow notch

174. McCall and Knox (1978)* report on the use of a low-flow notch design to provide fish habitat in a modified channel for Rock Creek in north-central Indiana. Although the modified channel followed the natural meandering alignment of the stream, it was some 65 ft wide and low flows were only about 1 in. deep. A low-flow notch about 6000 ft long was constructed by blasting the rock bottom of the stream. The smaller channel was placed as close to one side of the larger channel as

* Supplemented by personal communication, James D. McCall, U. S. Soil Conservation Service, Indianapolis, Ind., 16 June 1980.

possible to take advantage of riparian vegetation. Vertical relief was built into the small channel with pools 2.5 to 4 ft deep and riffles 0.5 ft deep. Some of the blasted material was placed in the large channel to force low flows into the notch or "fishway."

175. Field studies of fish populations revealed 23 species of fish in the low-flow notch 1 year after completion. Several species of gamefish and forage fish were collected. Only 16 species of fish were collected from the natural channel upstream from the fishway. Fish species numbers collected from the fishway for each of the following 4 years totalled 23, 22, 23, and 25. Greater diversity and abundance in the final sampling year may have been due to upstream construction (McCall and Knox 1978).

Floodways

176. A floodway is a larger channel constructed at an elevation intermediate between the stream channel and the top of the bank to convey high flows (Figure 29). Linder (1976) describes the use of composite channel geometry--a floodway consisting of high-flow berms on one side of the channel in straight reaches and flow cutoff channels across meander loops (Figure 30).

177. Environmental benefits of a floodway include the preservation of the original stream substrate and meanders. Instream cover, riparian vegetation, and vertical relief may all be kept in their natural state. A properly designed floodway will be inundated only during high flows, so it can be used for urban greenbelts, recreation, limited grazing, or wildlife management (Arthur D. Little, Inc. 1973).

178. Unfortunately, there are several limitations on the use of floodways. The use of floodways is limited to sites where the topography surrounding the stream is neither too rugged not too flat. Land requirements are higher for floodways and composite channels than an ordinary modified channel, and the floodway or composite channel is not as hydraulically efficient as a uniform channel.

179. Floodways require careful design and construction to maintain proper invert elevations. A floodway that is too low will be inundated too frequently and aggrade rapidly. The wet conditions will make

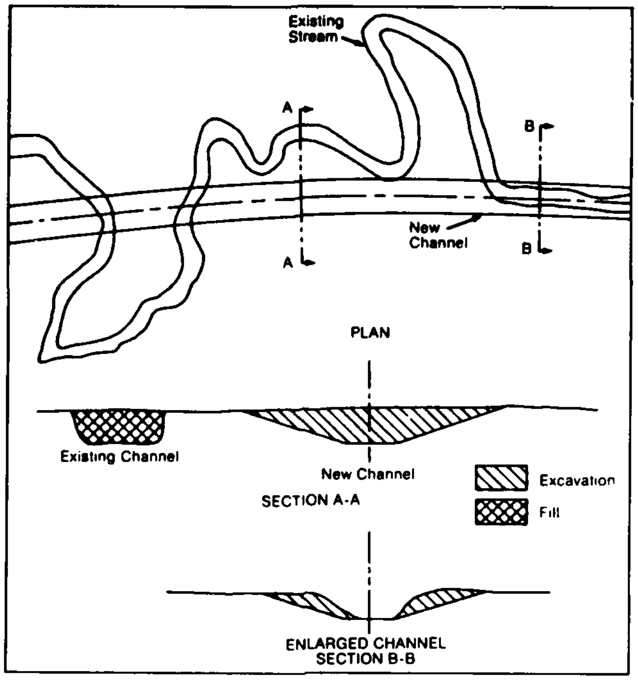



Figure 29. Floodway plan and cross sections

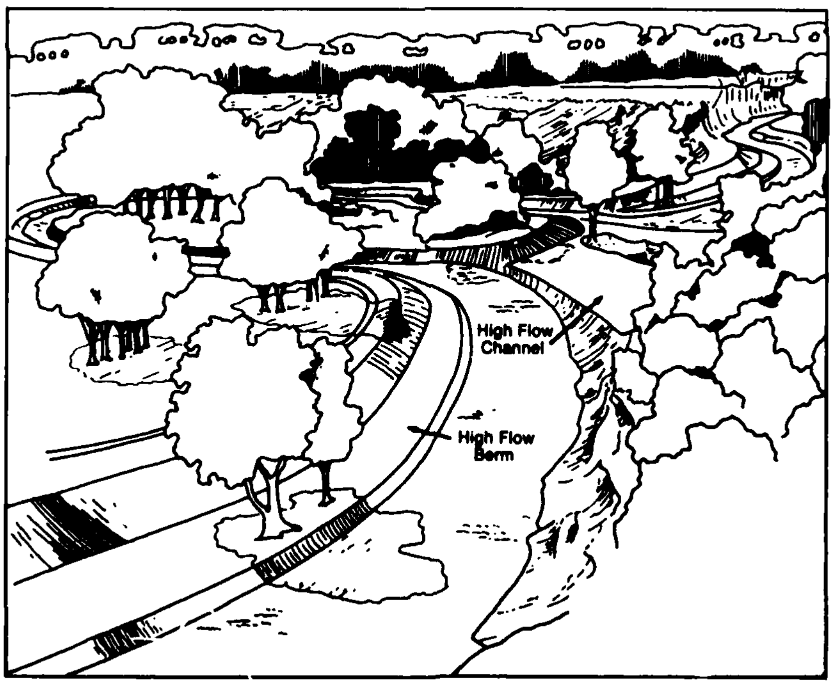



Figure 30. Composite channel geometry

it difficult to establish a good stand of grass in the floodway channel to keep it stabilized. Local inflows may also keep water in the floodway and thus hinder the establishment of grass. A floodway that is too high will not provide sufficient flood protection. Floodways are prone to degrade to the elevation of the existing stream channel and thus divert all flows--both low and high. Some type of grade-control structure must be provided at the downstream end of flow cutoff channels. Floodways are especially vulnerable to changes in invert elevations during and right after construction when soils are exposed and unstable conditions exist. Extensive damage was done to the Bear Creek floodway (built by the Tennessee Valley Authority (TVA)) in north Alabama during construction when floodwaters from a low-frequency event overtopped a temporary dike and scoured the floodway severely.*

Levees

180. Levees may be used in conjunction with or instead of other types of channel work, and are identified above as a structural alternative to channel enlargement. Levees have the advantage that they leave the natural channel untouched. They preserve the diversity of the existing aquatic habitat and the stability of the natural channel. Levees do require large land areas and sometimes relocation of buildings, bridges, utilities, etc. When levees result in substantial constriction of the natural floodway, floodwater elevations upstream of and within the leveed reach will be increased. Part VI of this report deals with levees.

181. The Canal Section of the Tennessee-Tombigbee Waterway, currently under construction, features an innovative use of levees known as the "chain of lakes" concept (Figure 31). The waterway is being excavated just east of, and roughly parallel to, several natural streams. A levee is being built between the canal and the natural streams to maintain flow in the natural streams and to keep floodwaters out of the canal. The east side of the canal is not leveed, but is formed by high

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* Personal communication, Frank Stansberry, TVA, Chattanooga, Tenn., 24 April 1980.

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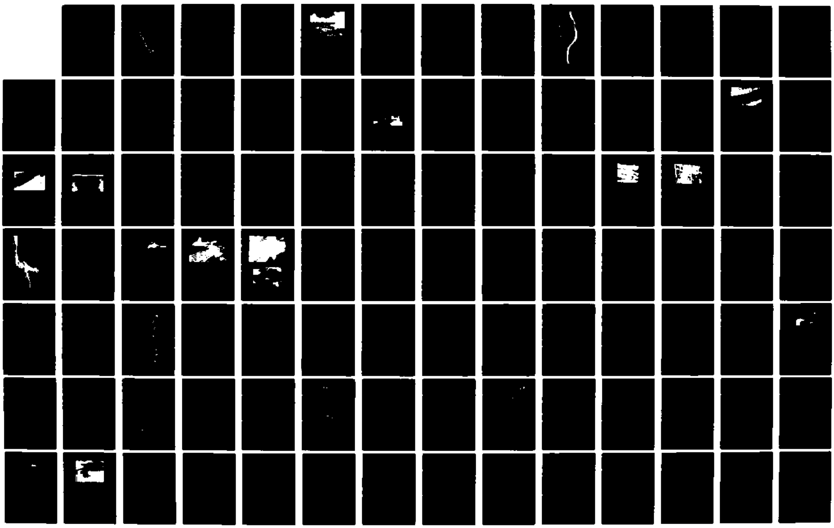

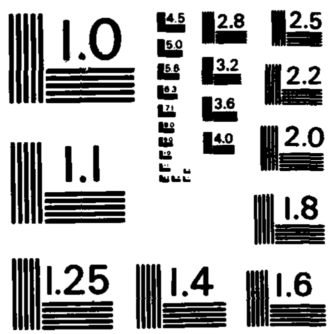
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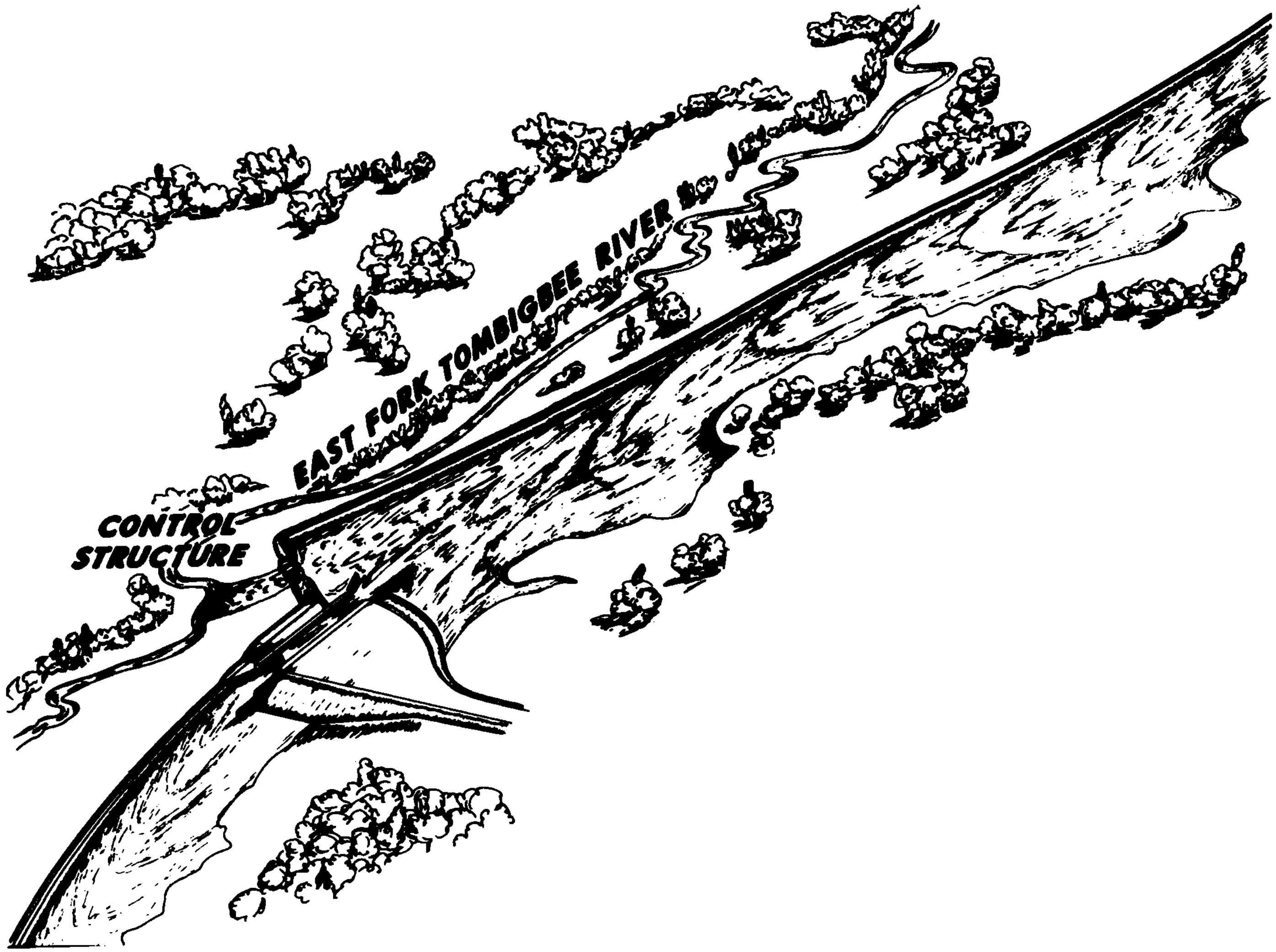



Figure 31. Chain of lakes concept for levees along the Tennessee-Tombigbee Waterway (drawing courtesy of U. S. Army Engineer District, Mobile)

ground. The east side of the canal thus has a gently sloping, irregular shoreline that provides shallow aquatic and littoral habitats. In order to maintain the integrity of the drainage basin, minimum flow structures supply water from the canal to several severed streams along the western side of the canal.

Fish berms

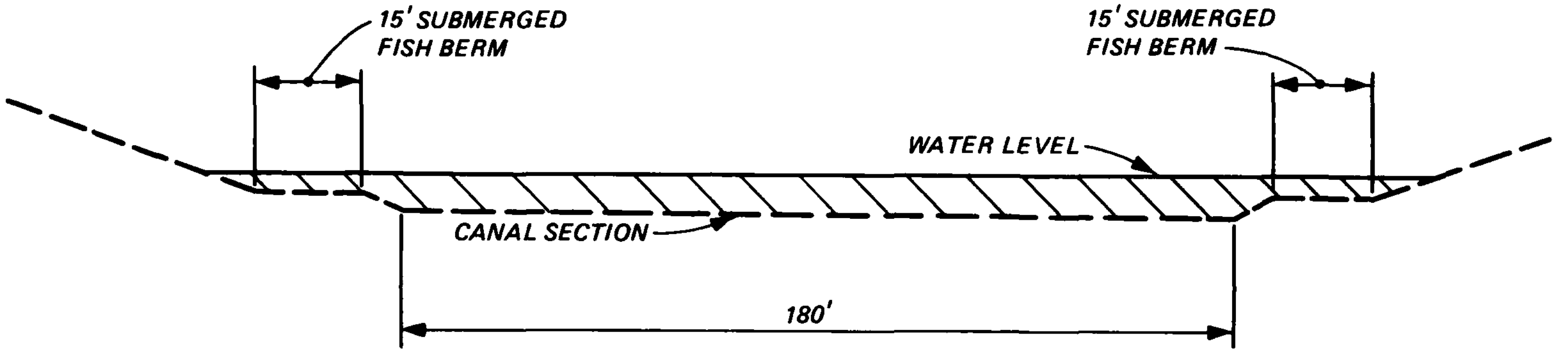
182. Enlargement of channels through marshy areas may eliminate shallow-water habitat. The use of a bench or step built into the side of the trapezoidal cross section is a proposed solution (Figure 32). "Fish berms," as they are called, are 5 to 15 ft wide and 1 or 2 ft below the water surface. The fish berms provide shallow littoral areas for emergent vegetation, fish breeding, and habitat for production of food organisms to support deepwater fish of the main channel (U. S. Army Engineer District, Jacksonville 1979). No information was found on the effectiveness of fish berms.

Single-bank modification

183. A portion of the natural aquatic and riparian habitat can be preserved by limiting modifications to one side of the stream (Figure 33). Single-bank modification necessitates using the existing alignment of the stream. Although single-bank modification has been used in conjunction with artificial structures and restoration, little quantitative information is available on its effectiveness. Obviously, single-bank modification will produce a rougher channel with less flow capacity than an equivalent channel modified on both sides. On the other hand, single-bank modification preserves at least half of the riparian vegetation with its associated shade and input of CPOM to the stream. Aesthetic impacts are reduced, and, in some cases the preserved vegetation maintains the stability of the unmodified bank. The benefits of single-bank modification can be enhanced by alternating banks from reach to reach, by preserving clumps of trees on the modified bank, and by prompt revegetation of the modified bank.

Management of cutoff meanders

184. As noted above in the discussion of the environmental impacts of alignment, alignment usually results in the cutting off of




·?TE: WATER LEVEL RANGES 1 TO 5
FEET OVER FISH BERM

Figure 3_. Fish berms (Berms provide shallow water habitat for fish and rooted plants and improve overall habitat diversity of channel.)

Figure 33. Single-bank modification (photo courtesy C. A. McConnell and the Soil Conservation Society of America)

meanders which are gradually isolated from the main channel by sedimentation, degrade biologically, and are eventually filled and cultivated or become terrestrial wildlife habitat. Management of cutoffs by controlling water flow and sedimentation may enhance and prolong their usefulness.

185. Nelson, Horak, and Olson (1978) describe a shallow impoundment built by isolating a cutoff channel on the Colorado River in Arizona. Deer Lake was built by installing dikes at either end. An outlet structure was installed at the downstream end and the cutoff area was dredged to increase water depth. The new lake has a surface area of approximately 100 acres. Although Nelson, Horak, and Olson (1978) evaluated Deer Lake as "an outstanding success, providing excellent habitats for fish and small game," no mention was made of measures to avoid stagnation. Periodic dredging of Deer Lake may be required to maintain depths.

186. An SCS channel modification project on Crow Creek, Tenn., and Ala., included a feature to maintain two cutoff meanders. Culvert intakes were installed upstream of each of the two cutoff meanders to supply them with water. Unfortunately, the culverts were above normal flow elevation and carried water only at high flows. The culverts were rapidly filled with sediment and eventually carried no water at all (Winger et al. 1976). A short-term field study conducted as part of EWQOS Project V included sampling cutoff meanders on the Verdigris River in Oklahoma. Some of the closure plugs used to isolate the cutoff meanders from the main channel were built with culverts to reduce stagnation within the cutoff reach.

## Summary

187. A typical unaltered stream is part of a relatively stable, diverse ecosystem characterized by: (a) a diversity of physical habitats, (b) a wide diversity of species, and (c) a complex interrelationship among the variables of channel morphology and the transport of water and sediment. Modification of the stream channel for drainage, flood control, or navigation results in intentional and unintentional changes in the physical characteristics of the stream channel. Adverse environmental effects of channel modification are ultimately related to these physical changes. Natural streams contain a diversity of current patterns, depth, light conditions, and substrate that supports a diverse community of organisms. Alteration generally results in reduction of habitat diversity which in turn causes a decline of species diversity.

188. Adverse environmental effects associated with channel modification include loss of valuable habitats or habitat diversity, channel instability, loss of aesthetic value, water quality degradation, and undesirable changes in the hydrologic cycle. The severity and nature of environmental impact varies considerably from one channel modification project to another. Channel modifications for flood control and drainage facilitate riparian land use changes.

189. The adverse environmental effects of modifying major rivers

are not as well understood as the effects of modifying lower order streams. One reason the basic ecology of large streams is not as well understood is that large streams are more difficult to sample. Immediate or eventual loss of backwater habitat (and thus a reduction in overall habitat diversity) is a major impact of some navigation channel modification projects.

190. In the absence of quantitative information, several individual designers have employed intuition or unproven ideas to reduce environmental impacts of channel work. Additional ideas have come from conservation agencies and citizens groups. These innovations constitute the primary base of information on design alternatives to reduce the environmental impacts of stream channel modification. The innovations may be categorized as: (a) restoration of an earlier, higher flow capacity by selective clearing and snagging, (b) the use of instream structure to increase habitat diversity, (c) the use of modified cross sections, or (d) management of cutoff meanders. All of these measures have shown promise, but relatively little work has been done to quantify their effectiveness. More information is also needed on the cost and hydraulic performance of these methods.

# PART IV: DIKES

## Introduction

191. Dikes are free-standing structures of stone, pile clusters, or pilings with stone fill placed within waterways either parallel to the channel or transverse to it. The main purpose of dikes is to concentrate the flow into a single channel and to develop and maintain desired channel alignments and depths during low-flow periods. Dikes are used on navigable alluvial rivers as part of an overall river training or river stabilization scheme for the entire river system. Dikes may thus be used in conjunction with other measures such as floodways, bank protection, cutoffs, and levees to control floods, maintain navigation channels, stabilize banks, and develop harbors (Morris and Wiggert 1972).

192. This Part describes the various types of dikes presently in common use on the nation's waterways. A brief review of CE dike design and construction practice is followed by discussion of the environmental impacts of dikes. Dike notching, a technique used to reduce some of the adverse environmental impacts, is described and evaluated. This Part concludes with a review of relevant ongoing research and a summary.

## Purposes and Descriptions of Dikes

193. As noted above, dikes are used to concentrate streamflow into a narrower, deeper channel. Flow constriction results in temporarily increased velocities which tend to minimize sedimentation in the navigation channel, thereby reducing dredging requirements. Although this is the simplified concept of dike design, many subtle relationships such as movement of sediment by secondary currents and the effects on alignment of flow are involved in the design of dikes and the associated river response. A general illustration of this concept is shown in Figure 34. When used in conjunction with revetment or bank stabilization structures, dikes may be used to deflect flow away from unstable banks

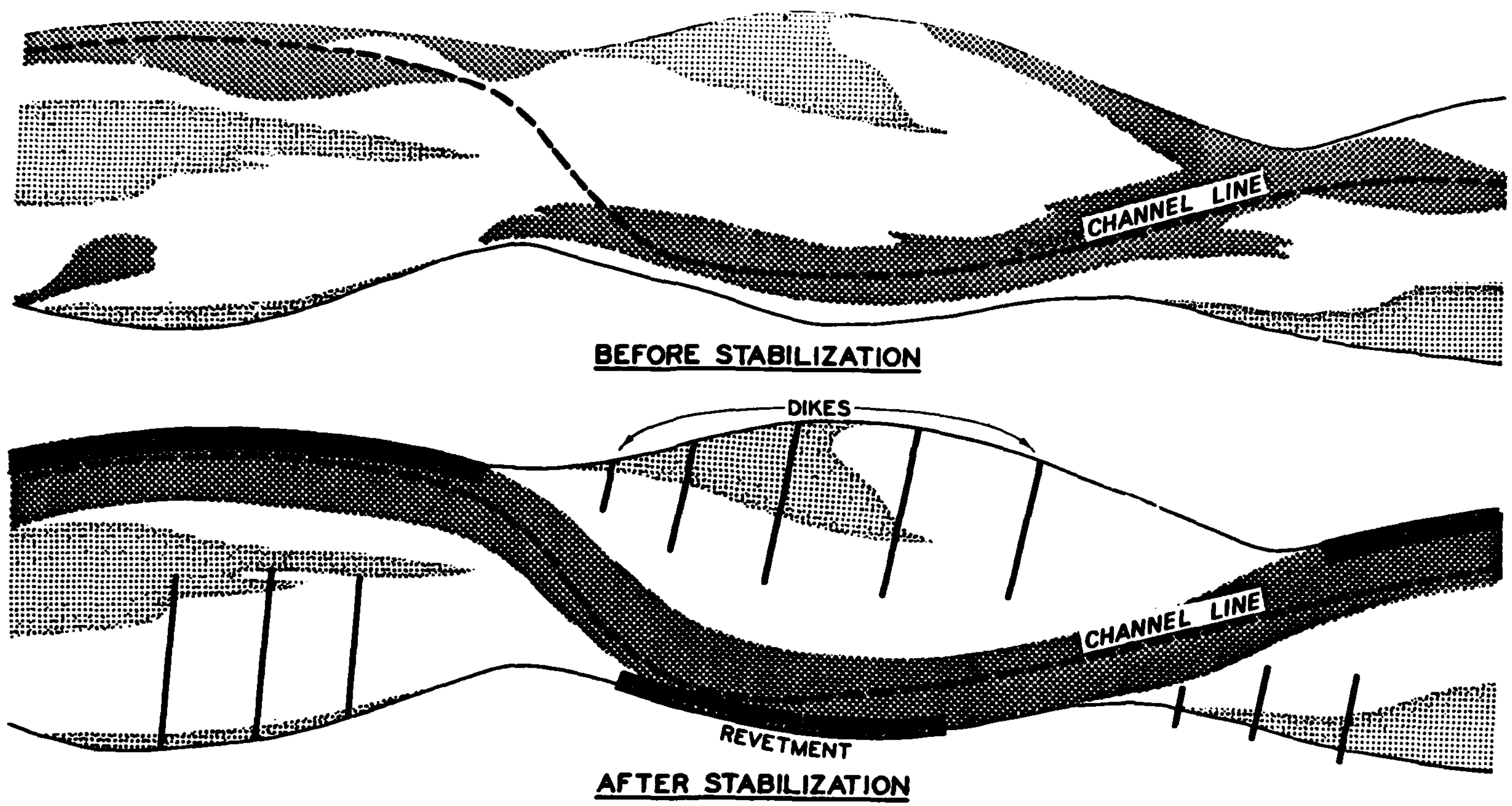



Figure 34. River stabilization plan for a reach of the Lower Mississippi River (after Moore (1972))

to reduce bank erosion and protect levees. Although a variety of materials have been used in the past for dike construction, stone dikes are by far the most common type currently used (Pokrefke 1978a). Discussion in this report is limited to stone dikes.

194. The CE Districts involved most intensively in dike construction are those within the Lower Mississippi Valley Division (LMVD) and the Missouri River Division (MRD). The alluvial characteristics of these rivers (i.e., high bed load, tendency to meander) have required both constriction and stabilization to aid navigation and prevent loss of land and destruction of levees. General project authorizations are granted for construction of works necessary to maintain the desired alignment of the river, thereby maintaining the integrity of the flood control system and an adequate navigation channel.

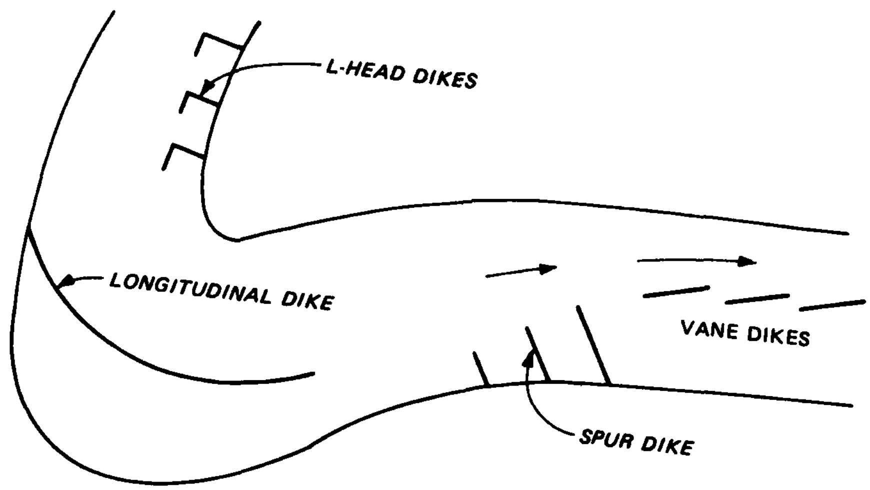
195. Several distinct types of dikes are used individually and in combination to achieve a specific desired result. Terminology used to describe various dike types varies from region to region, as indicated by Figures 35a and 35b. Descriptions of dike types and their use are given in EM 1110-2-1611 (U. S. Army, Office of the Chief of Engineers 1980b) and are summarized below.

Spur dikes

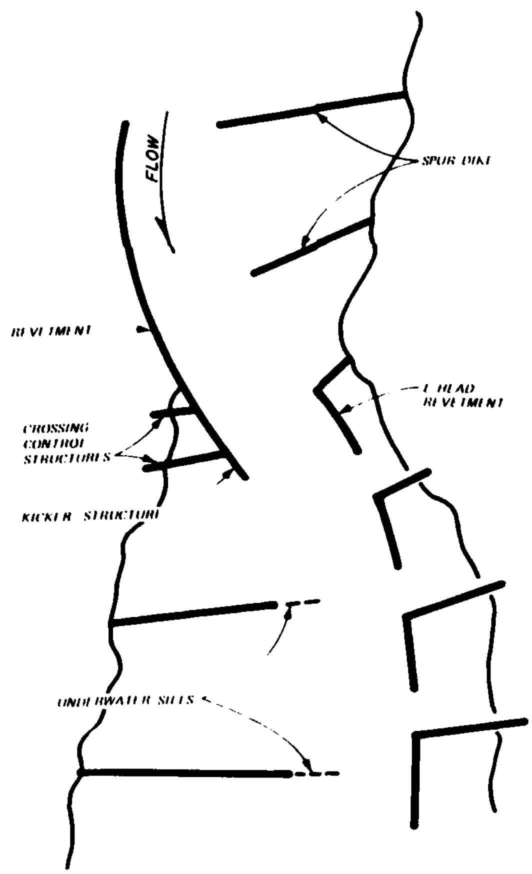
196. Spur dikes, also called transverse or cross dikes, wing dams, or jetties, are the most common type of dike used on major streams. These dikes are normally used in groups which are aligned approximately perpendicular to the direction of the channel flow and extend outward from the bank toward the center of the channel, as shown in Figure 35a. The primary purpose of spur dikes is to concentrate the flow into a single channel section during low flows. This produces a tendency for the river to stay within the constricted reach, thereby reducing both new work and maintenance dredging requirements. Significant deposition of sediment between adjacent spur dikes is a major environmental concern and is discussed in detail in following paragraphs.

Longitudinal dikes

197. Longitudinal dikes, also called revetment, extend generally downstream and parallel to the direction of flow, as shown in Figure 35a.




a. Types in general use (after U. S. Army, Office of the Chief of Engineers (1980b))




b. Dike types used on Missouri River

Figure 35. Dike types

They are used to reduce the curvature of sharp bends, develop stable channel alignments, and provide erosion protection for the adjacent bank. Unlike transverse dikes which purposely provide high resistance to flow, longitudinal dikes provide a gradual transition and offer less resistance.

Vane dikes

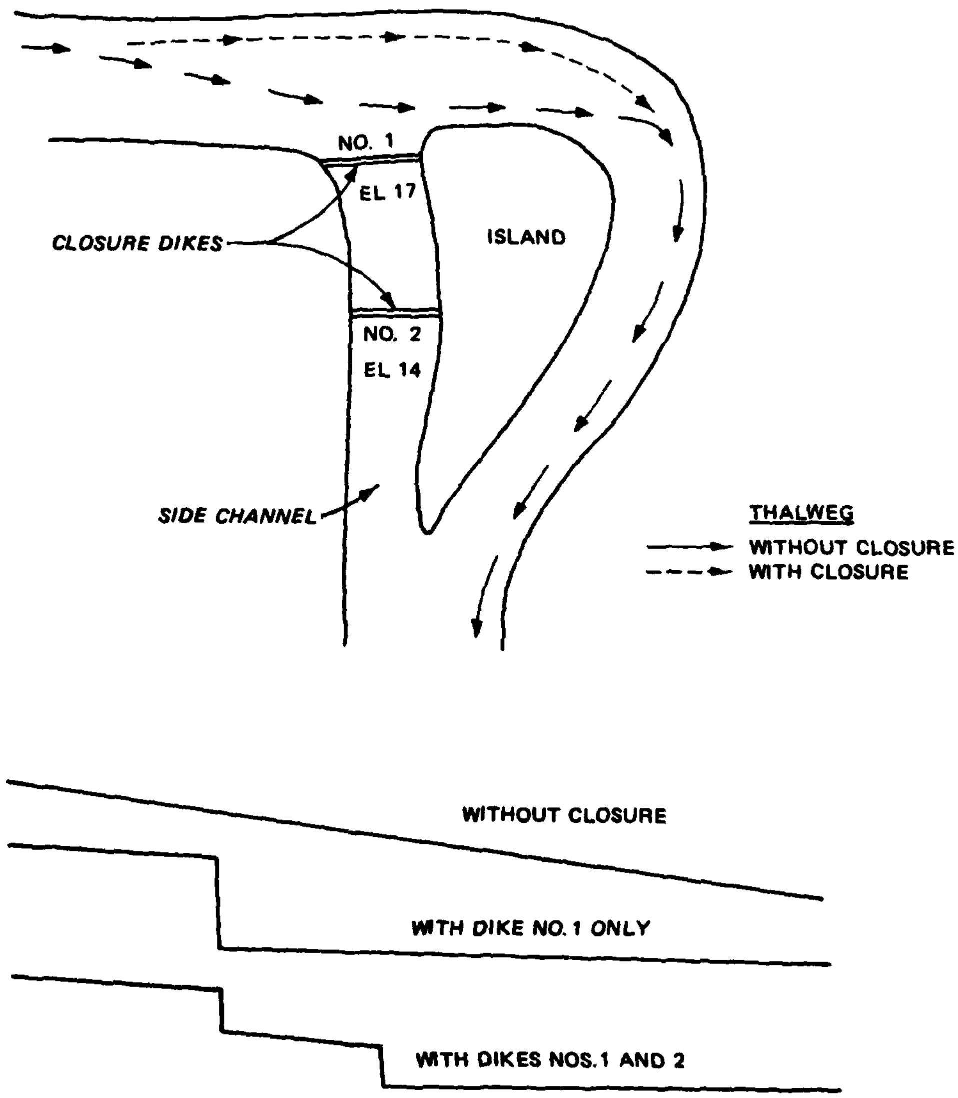
198. Vane dikes extend generally parallel to the direction of flow but are located within the channel and do not abut the bank, as shown in Figure 35a. By slightly angling the vane dike alignment with the direction of flow, the vanes act to develop a lateral differential in the water level without creating an unduly high resistance to flow. Vane dikes are sometimes used as downstream extensions to spur dike systems (L-head dikes).

L-head dikes

199. L-head dikes are a variation on the spur dike concept and consist of a spur section running roughly perpendicular to the direction of flow and a connected L-section extending downstream roughly parallel to the flow, as shown in Figures 35a and 35b. The addition of an L-section to a spur dike with crest elevation either higher or lower than the spur tends to reduce accretion behind the dikes and therefore can be effectively located to block sediment buildup in critical areas such as harbor entrances. If the L-section is about 2 ft lower than the spur, scour will occur parallel to the inside of the L-section. Care must be taken to build the L-section high enough to block bedload, though. An L-section with a crest high enough that it is rarely overtopped also reduces accretion, particularly when the spur section is notched. When used in a spur system, the addition of L-sections allows wider spacing of dikes, but successful design of L-head dikes is more difficult.

Closure dikes

200. Closure dikes are used to reduce flow in secondary channels in divided reaches, thereby more fully developing the desired channel alignment. Two or more such closure dikes are sometimes used to "step" the differential head through the side channel and thus reduce downstream scour, as shown in Figure 36.




WATER-SURFACE PROFILES (SIDE CHANNEL)

Figure 36. Side channel closure (after U. S. Army, Office of the Chief of Engineers (1980b))

201. Closure dikes can also be used to prevent sediment deposition in bendways created by engineered cutoffs. Such areas are valuable from a recreation and fish and wildlife standpoint, and these resources are better preserved by prevention of excessive sediment deposition. The closure is usually accomplished across the upstream bendway entrance, and spur dikes are located in the downstream entrance as shown in Figure 37.

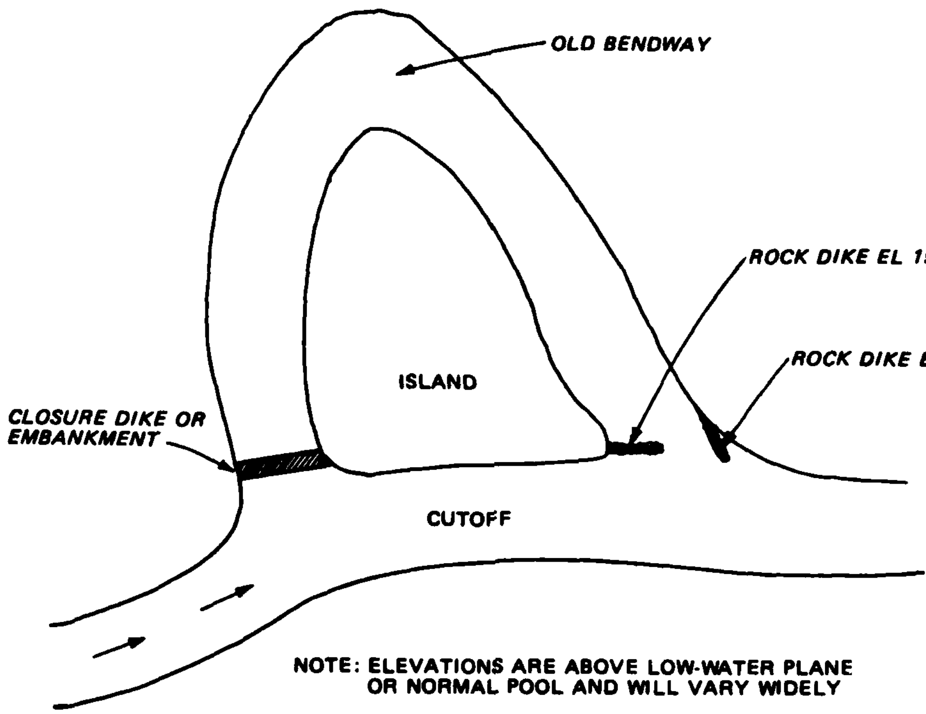



Figure 37. Cutoff bendway closure (Dikes are installed to minimize sediment deposition in severed meander. The severed meander may be used as a harbor, for recreation, or fish and wildlife habitat (after U. S. Army, Office of the Chief of Engineers (1980b))

## Design and Construction of Dikes

### Design

202. Little formal guidance has been developed for design and construction of dikes. A symposium held at the U. S. Army Engineer Waterways Experiment Station (WES) revealed that design practices vary widely among CE Districts/Divisions actively engaged in dike construction. However, certain basic similarities in overall design criteria and guidance

are noted. An excellent historical review of the development of dike design and construction practice within various Districts is contained in the symposium minutes (Pokrefke 1978b).

203. On larger river systems, general placement and construction sequencing for dike systems is dictated by master plans. Both placement of dikes in the master plan and the design of a given dike or group of dikes is largely dependent on river conditions at the time of design and on the past experience and judgment of the individual design engineer.

204. For many years, the major consideration in dike design was to induce sedimentation between dikes, under the assumption that this would result in the most efficient reduction of sedimentation in the navigation channel. Recently, some attention has been given to maintaining limited flow or open-water areas between dikes for flood conveyance and environmental reasons. This trend is discussed in detail in following paragraphs.

205. Basic design parameters for spur dikes are shown in Figure 38. Many of the parameters are dictated by the desired placement of the dike to achieve a desired channel alignment and others are beyond the designer's control. Some parameters, however, can be deliberately varied according to the wishes of the designer. Brief discussions of the major design parameters (Pokrefke 1978b, U. S. Army, Office of the Chief of Engineers 1980b) are given in the following paragraphs.

206. Channel alignment. Channel alignment is determined by a master plan. This is probably the single most important design parameter and relies most heavily on the judgment and past experience of the designer. Actual alignment for given reaches is dependent on many factors, including the desired degree of curvature for bends, the tendency of the stream to meander, fixed points such as rock outcroppings, and facilities which must be protected.

207. Length. Length (Figure 38) of spur dikes extending into the channel is a function of the desired navigation channel width and desired width of the constricted channel. These widths and consequently the dike length vary according to the river system in question and navigation requirements. Values for constricted channel widths of some major river systems are as follows:

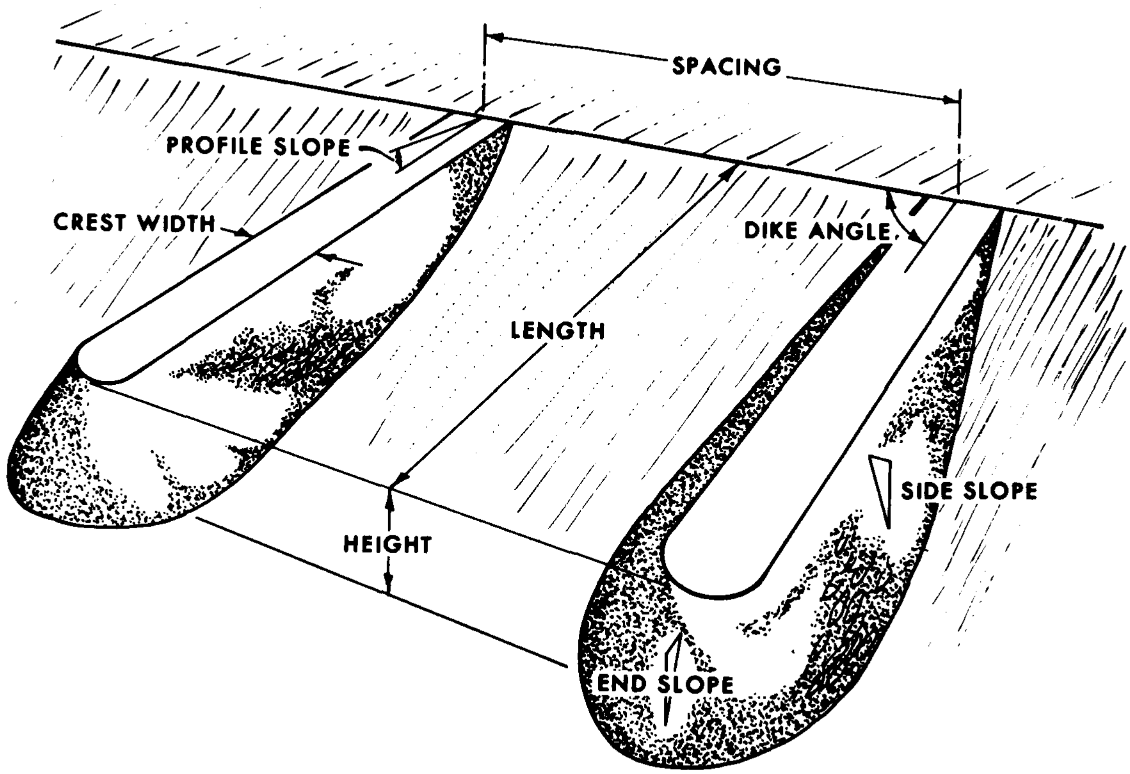



Figure 38. Basic design parameters for spur dikes

| Stream | Channel Width |
|---|---|
| Lower Mississippi River | 2500 to 3000 ft |
| Middle Mississippi River | 1500 ft |
| Arkansas River | in-bank river width |
| Missouri River | |
| Sioux City-Rulo, Neb. | 600 ft |
| Rulo, Neb.-Kansas River | 700 to 800 ft |
| Kansas River-Grand River | 800 to 900 ft |
| Grand River-Osage River | 900 to 1000 ft |
| Osage River-Mouth | 1000 to 1100 ft |

208. Major considerations in establishing such constricted widths are: (a) the channel must adequately convey high-water flows; (b) flow velocities must not be unduly increased; (c) the flow must be sufficiently constricted to prevent a tendency to meander within the dike system; and (d) sufficient scouring action must be induced to maintain

the navigation channel without excessive dredging (U. S. Army Engineer District, Omaha 1964). Striking a balance between these some times conflicting principles requires a high degree of experience and judgment.

209. Height. Dike height (Figure 38) is normally referred to as an average height above some developed reference plane. For the Mississippi River, the Low Water Reference Plane (LWRP) is used. The LWRP is a parallel low water reference plane based on an accumulated past record of minimum stages and flows. On the Missouri River, the Construction Reference Plane (CRP) corresponds to the flow that is equaled or exceeded 75 percent of the time during the ice-free navigation season. By using LWRP, CRP, or some equivalent reference, all dikes along a given reach can be theoretically designed so as to be overtopped a specified number of days per year. Typical dike heights for some waterways are as follows:

| Stream | Height |
|---|---|
| Arkansas River (Tulsa District) | Equal to that of natural bars or 2 to 3 ft above average navigation pool |
| Arkansas River | 10-13 ft above LWRP |
| Missouri River | 2 ft below to 4 ft above CRP |
| Lower Mississippi River | 15 ft above LWRP |

210. The difference in height of adjacent dikes is normally in the form of a stepped-down configuration in the downstream direction. Stepped-up configurations are often used on the Lower Mississippi River in stabilization of bars which naturally tend to increase in elevation moving downstream. The overall design should be compatible with the hydraulic and sediment transport characteristics of the channel geometry at the location in question.

211. Profile slope. The profile slope for dikes (Figure 38) is normally level. Profile slopes in a downward configuration toward the navigation channel are sometimes employed if increases in the contracted width can be tolerated at higher stages. This practice also tends to lessen scouring and undercutting around the end of the dike. Downward sloping profiles can be constant over the entire length of the dike or

may extend only over a partial length. Where dikes must cross deep side channels, weir-type sections are frequently used. Recently, notching of the dike profile has been suggested as a possible method for reducing accretion deposits and thereby benefiting flood conveyance and aquatic habitat. Dike notching is discussed in more detail in following paragraphs.

212. Crest width. Crest width of dikes (Figure 38) usually is a function of the volume of stone necessary to withstand anticipated scour. Dikes constructed by end dumping stone from trucks require a minimum crest width of about 14 ft, while those constructed by barge dumping normally have crest widths of 3 to 10 ft. At times variable crest widths corresponding to a specified stone weight per linear foot are specified for dike construction. A minimum crest width of about 5 ft is required to ensure that floating debris or ice will not dislodge stones, causing raveling of the crest, and to ensure that sufficient stone is available to armor the downstream plunge pool.

213. Dike angle. Dikes are usually placed normal to the direction of flow. Dikes on the Missouri River are usually angled 10 to 22 degrees downstream (U. S. Army Engineer District, Omaha 1964). The dike angle greatly influences the tendency for scour at the end of the dike. Upstream angles are usually avoided since the added resistance to flow encourages scouring.

214. Side and end slopes. Side slopes (Figure 38) for dikes are normally 1V on 1.25H to 1V on 2H. This range of side slope angles closely corresponds to the natural angle of repose of stone placed in water. End slopes of dikes may be somewhat flatter than the side slopes to reduce the tendency to scour. End slopes as flat as 1V on 10H are used on the Mississippi River.

215. Stone size. The stone used for dikes is usually quarry-run, therefore stone gradation will vary depending on the source. Specifications may require gradation for quarry-run stone to fall within certain gradation bands. Also certain portions of the dike (e.g., stone fill or outside layer) may require differing gradations. Typical specifications for stone size used on the Lower Mississippi River are shown in Figure 39

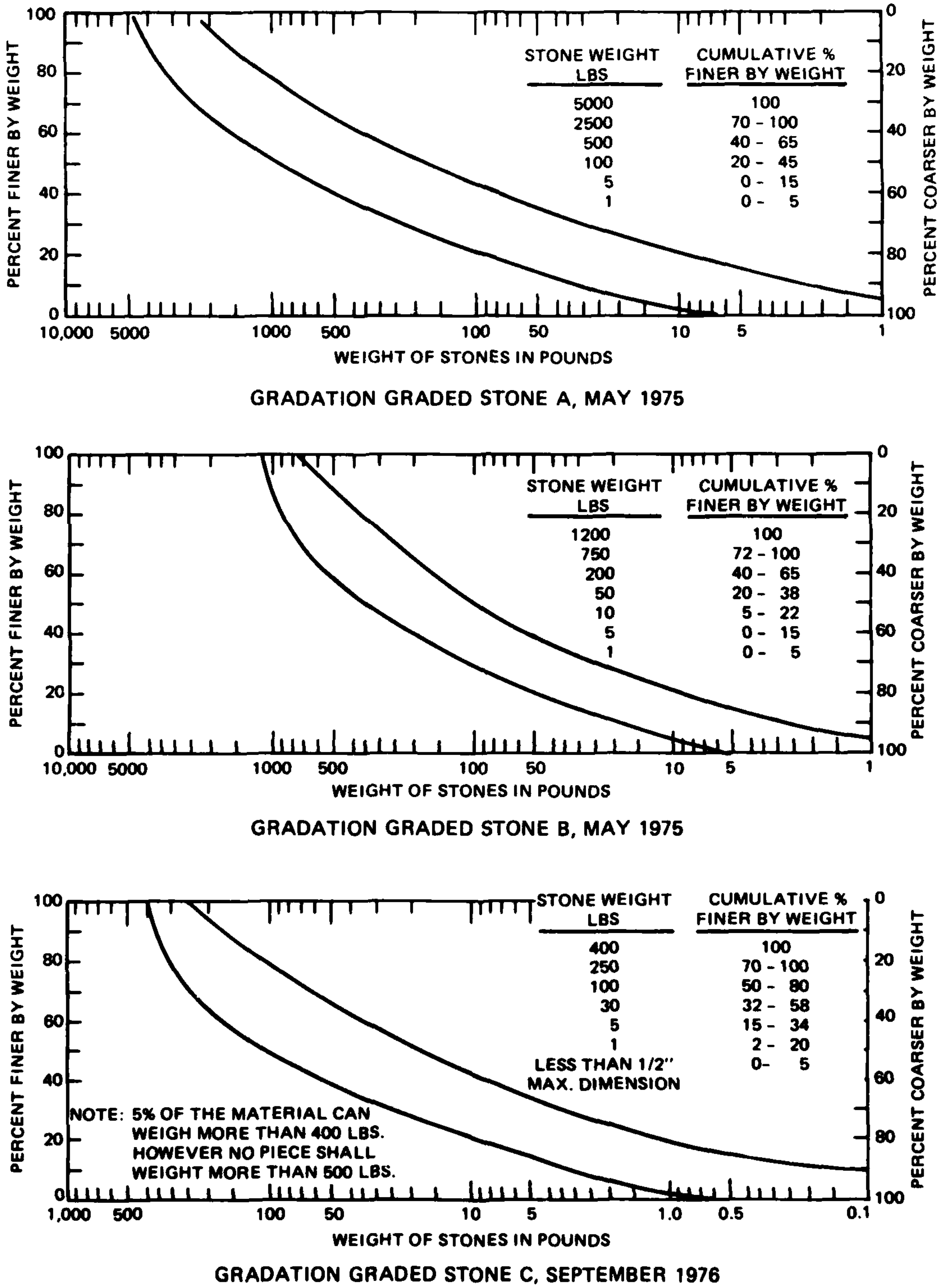



Figure 39. Typical stone gradation for Lower Mississippi River dikes (after U. S. Army Engineer Division, Lower Mississippi Valley (1979))

(U. S. Army Engineer Division, Lower Mississippi Valley 1979). Graded Stone A, the coarsest of the three gradations shown, is used most frequently in dikes.

216. Spacing between adjacent dikes. Spacing between adjacent dikes varies from one-third the length of the upstream dike to three to four times the length of the upstream dike. Spacing is usually set close enough to prevent the tendency of the stream to meander between dikes.

## Construction

217. Construction of dikes requires a limited amount of bank preparation in the form of clearing, grubbing, and bank grading. Excavation for a "root trench" or keyed dike section at the point of intersection with the shore is required. Construction of the major length of dike is normally accomplished by end-dumping stone from trucks or dragline placement from barges, as shown in Figure 40.

Figure 40. Dike construction using barge-mounted dragline

218. A typical construction sequence example can be summarized from LMVD guide specifications (U. S. Army Engineer Division, Lower Mississippi Valley 1979) for dikes. Prior to actual placement of the dike stone, the bank is first cleared, grubbed, and snagged at the point of intersection of the dike and for required distances where bank protection will be placed. Clearing consists of removal of all trees, brush,

and obstructions that would hinder subsequent grading and excavating. Specifications normally prohibit unnecessary clearing in areas not directly interfering with the work. Grubbing refers to removal of buried stumps, limbs, and roots to the finished grade or a specified distance below finished grade. Snagging is the removal of all in-water stumps, limbs, or obstructions along the entire area to be covered by the dike proper.

219. If barge placement of stone is used, piles are then driven at intervals along the dike alignment as required for alignment control or mooring the barges. Timber piles are normally used and "clumped" to provide a suitable mooring point. Typical arrangements of pile clumps are shown in Figure 41.

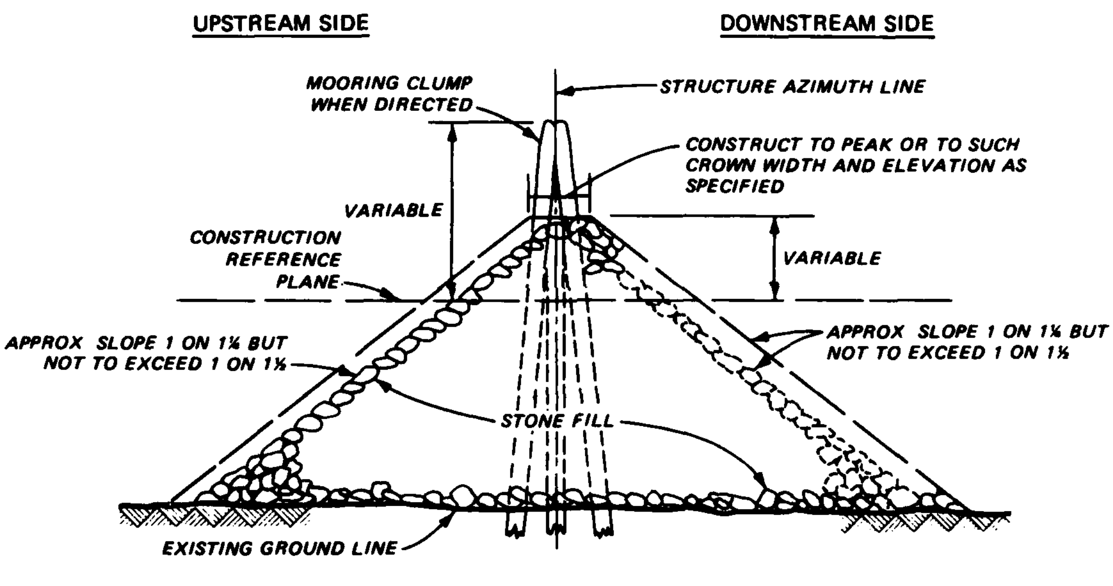



Figure 41. Pile clumps in stone dike cross section (after U.. S. Army Engineer District, Omaha (1964))

220. Bank grading is required at the point of dike intersection and in areas where bank protection is required. Slopes are graded to that required by slope stability considerations. Grading is required for the entire bank landward of the waterline. Subaqueous grading is specified a given distance below the LWRP to provide a smooth transition

between the upper-bank and lower sections of the dike. Excavation is also required at the dike-bank intersection in the form of the "root dike trench" or key trench. When filled with stone, this key trench provides a firm tie with the bank.

221. Placement of stone for the dike section usually proceeds from the bank outward. The full dike section may be advanced by maintaining a blanket of stone several feet thick in advance of the full dike section for a suitable distance. The entire dike length may also be constructed in lifts, placing a given thickness of stone for the entire length, then repeating the process until the full dike section is completed. The stage method of construction may also be extended over several seasons, avoiding an abrupt completion of the construction and excessive scouring at the ends of the dikes. This method also takes advantage of sediment accretion and may result in reduced stone requirements.

## Environmental Considerations

222. The environmental impacts of dikes and the influence of various dike designs on environmental quality have not yet been quantified. A recent symposium on dike design (Pokrefke 1978b) and studies conducted for environmental assessment of certain waterways (Johnson et al. 1974, Solomon et al. 1975) have pointed to the need for developing and evaluating dike design and construction techniques that would improve environmental quality. Two areas of concern regarding the environmental considerations of dike design and construction have been identified (Thackston and Sneed 1980, Johnson et al. 1974):

- a. Varied impacts associated with the dike construction activity.
- b. Changes in water surface area and aquatic habitat resulting from completed dikes.
- c. Increased water-level fluctuation for given flows (due to combined effects of dikes and levees).

### During construction

223. Generally, the environmental impact associated with the

construction of dikes is of minor significance and some effects may be offsetting. Obviously, there is destruction of bottom habitat resulting from the placement of the stone itself. Also, the construction activity required for bank preparation and access may result in localized increases in turbidity due to erosion (Institute for Water Resources 1980).

224. Present data indicate that the main channel or navigation channel of a river is characterized by strong currents and shifting sand bed loads, which limits the usefulness of the channel as aquatic habitat (Johnson et al. 1974). Placement of stone for dikes in these areas would therefore have a minor effect on benthic organisms. However, it should be noted that the majority of dike construction does not lie in the main channel, but in depositional zones which are transient and depend on stage. Since benthic drift is deposited in such areas, they are possibly important feeding habitat for fish (Mathis et al. 1981).

225. Bank preparation may temporarily increase turbidity near the site. However, ambient turbidity levels may be high and any resulting increases would be of a temporary nature (Institute for Water Resources 1980, U. S. Army Engineer District, Vicksburg 1976).

After construction

226. Following placement of the stone fill, the dike structures act as a favorable influence on the aquatic habitat. The areas between stones and downstream of the dike may provide fish with food sources, resting areas, and refuge from predators (Institute for Water Resources 1980, Daley 1977, Johnson et al. 1974, Solomon et al. 1975). The stone also provides a stable substrate for macroinvertebrates (Mathis et al. 1981). The slack-water areas between dikes provide a habitat similar to natural backwater areas and sloughs. However, this desirable feature may only be temporary if significant sedimentation occurs between dikes.

Resulting physical changes in waterway system

227. The purpose of constructing dikes is to provide a channel constriction, thereby inducing scour to deepen the navigation channel. In some cases this process results in sediment accretion and loss of

water surface area between adjacent dikes during low flows. The effects of these physical processes on the riverine aquatic community are not well understood. Furthermore, the effects vary significantly depending on the hydrologic character of the stream in question. Reduction of water surface area, especially the shallow-water areas between the navigation channel and the bank, will reduce available habitat for plants and animals adapted to natural conditions (Johnson et al. 1974). The main environmental considerations associated with dikes are therefore: (a) reduction in areal extent of aquatic habitat and (b) ultimate reduction in habitat diversity.

228. The loss of areal extent of aquatic habitat is sometimes progressive in nature (Thackston and Sneed 1980). Sediment-laden waters which enter slack-water areas between dikes are slowed, allowing sediment to deposit. Gradual buildup of sediment during successive high flows results in a bottom level between dikes which is higher than the water level during low flow. This allows fast-growing vegetation, such as willows, to invade and grow during low-flow periods, stabilizing the sediments. The resulting increased roughness provides more resistance to flow, inducing even more sediment accretion during high flows. The end result of this process is a significant decrease in the area and types of aquatic habitat and an increase in the area of terrestrial habitat. Impact is especially significant if the accreted land is later converted to agricultural use.

229. Dike design parameters that most directly affect the gross magnitude of sediment accretion at a particular location are dike alignment, dike spacing, profile slope, and dike height. The degree and nature of sediment accretion due to the individual effect of each of the parameters are not yet known and are probably site-specific.

230. The problem of sediment accretion and subsequent loss of water surface area must be examined in light of the physical changes that would normally occur in large river systems. While losses of water surface area may be evident in comparing so-called "present-day" conditions with a given past "natural" condition, a similar comparison with a second past "natural" condition may indicate no significant loss of water

surface area or perhaps a gain. This illustrates the significant physical changes which occur naturally and continuously in river systems.

231. Changes in habitat diversity may also result from long-term physical changes in the waterway system. Natural meandering of an alluvial stream results in creation and destruction (filling in) of backwater areas over time. Dike construction, coupled with bank protection, prevents meadering, tending to stabilize the channel alignment. No new off-channel habitats are created; and, once existing ones are filled by sedimentation, habitat diversity is lost.

232. Qualitative descriptions of the physical changes observed in several major waterway systems are discussed in the following paragraphs. These discussions concern changes in gross water surface areas, which do not necessarily correlate directly with specific aquatic habitats.

233. <u>Lower Missouri River.</u> A comparison between river conditions in 1879 and 1972 on the Lower Missouri River indicates an estimated 50 percent of the water surface area has been lost (Funk and Robinson 1974). Much of the lost area has been converted to agricultural use. Accretion between dikes naturally developed in shallow-water areas and eliminated much of the shallow-water areas along the convex shoreline of the river flow-way (U. S. Army Engineer District, Omaha 1975). The upstream areas of many dikes have accreted, while downstream areas have not (Figure 42). This process sometimes leaves shallow pool areas downstream of the dikes. An extensive effort has been made to reduce the rate of accretion in the Missouri River dike fields.

234. <u>Upper Mississippi River.</u> The 9-ft navigation channel on the Upper Mississippi River above St. Louis, Mo., now features an extensive lock and dam system. However, prior to 1930, a 6-ft navigation channel was maintained by constructing an extensive system of dikes. In 1968 a dike maintenance program was initiated for bank stabilization and to ensure against degradation of the dike system.

235. A study conducted for the U. S. Army Engineer District, St. Louis (Simons et al. 1975) provides some basic information regarding changes in surface area, over an extensive time period, for an area now

Figure 42. Sediment deposition pattern in a Missouri River dike field (Direction of flow is from right to left.)

encompassed by lock pools 24, 25, and 26. The definition of river surface area used in the study is that area between the riverbanks. Islands were defined as areas of land-type vegetation separated from the mainland by channels. Riverbed areas were defined as river surface area less island area.

236. The river condition was first defined by township surveys in the early 1800's. By 1878 a systematic improvement program of the Upper Mississippi had been implemented consisting of chute closures, revetment, and dikes. Conditions from an 1891 survey indicate a decrease in river surface area of 4.1 percent between the early 1800's and 1891.

237. In 1905, a 6-ft project was authorized and an extensive dike construction program was initiated. Comparison of 1891 and 1929 surveys indicates a river surface area loss of 1.9 percent. Following authorization of a 9-ft project in 1930, a system of locks and dams was constructed. A comparison of 1973 and 1928 conditions indicates a gain in river surface area of 11 percent, primarily due to the submergence of former floodplain areas. These data indicate only a minor change in overall river surface area due to the diking program on the Upper Mississippi.

238. Middle Mississippi River. Snagging on the Middle Mississippi River from St. Louis, Mo., to Cairo, Ill., was initially authorized in the early 1800's. By 1881 a comprehensive plan for regulation was approved, calling for improvement of the navigation channel by constricting the channel width to 2500 ft, and later authorizations called for a 9-ft-deep, 300-ft-wide navigation channel. An extensive dike system evolved, with a majority of the dikes being constructed between 1927 and 1944. Work now centers on maintenance and extensions to existing dikes to reduce the contracted width to 1500 ft.

239. A study conducted for the U. S. Army Engineer District, St. Louis (Simons et al. 1974) compared 1888 river conditions with 1968 conditions. Based on this comparision, the river surface area showed a reduction of approximately one-third. However, comparison of 1821 conditions to 1968 conditions showed river surface area to be approximately the same. This discrepancy was explained by other writers as the result of earlier clearing of trees adjacent to the riverbanks between 1824 and i883 in an attempt to remove the source of potential snags (Strauser and Long 1976, Westphal and Clemence 1976). Removal of the trees induced changes in bank slope and subsequent increases in river surface area. This discussion points out the fact that great care must be taken in drawing conclusions based on comparisons of river conditions.

240. Lower Mississippi River. Since the late 1800's a comprehensive river stabilization program on the Lower Mississippi River has been developed to increase the flood-carrying capacity of the river and to improve the alignment and depth of the river for navigation purposes.

241. Cutoffs, levees, dikes, revetments, and dredging are all used in combination on the Lower Mississippi River. Dikes as long as 3000-4000 ft have been built in an effort to constrict the channel from original widths as wide as 2 miles to a stable navigation channel 2500-3000 ft wide.

242. Data contained in Mississippi River Potamology studies (Winkley 1977) indicate that a 107-percent increase in top bank width has occurred between 1821 and 1975. This would imply a large gain in water surface area. However, no geomorphic study has been made which

indicates changes in water surface area directly due to dike construction. Figure 43 shows accretion at one point within the Greenville Reach (river mile 550 to 532). It is evident that accretion between dikes on the Lower Mississippi is extensive, but the relationship of this accretion to changes in the water surface area of the overall river system is not known.

Figure 43. Sediment accretion, Ben Lomand dike field, Lower Mississippi River

## Notched Dikes or Environmental Gaps

243. The concept of creating notches or gaps in new or existing dikes along the Missouri River to restore aquatic habitat was initiated in the Missouri River Division, CE. Now both the Omaha and Kansas City Districts, CE, use notches extensively. A similar program has also been adopted on a limited scale in the Middle Mississippi River by the St. Louis District, CE. Thackston and Sneed (1980) present a more detailed account of the historical evolution of dike notching programs to date.

244. The notches or gaps are created by removing stone for set widths and depths from existing dikes, leaving notches in damaged dikes,

or leaving notches in new dikes. A typical notch is shown in Figure 44. The flow through the smaller notches in Missouri River dikes has been observed to induce the formation of small chutes and submerged bars, thereby partially restoring shallow-water areas between dikes. However, where the notches are large, large flow through the notches results in an open-water type of habitat in the dike field. Higher grade stone is sometimes used to line notches to reduce future maintenance requirements.

Figure 44. Typical notched dike (photo courtesy of U. S. Army Engineer Division, Missouri River)

245. Sediment depositional patterns resulting from the dike notches on the Missouri River vary with location of the notch and shoreline conditions. Typical patterns are illustrated in Figure 45. These patterns indicate a desirable diversity in the type of shallow-water areas that result from the notches (U. S. Army Engineer District, Omaha 1977). Also, the notches appear to have no effect on the primary purpose of the dike fields, which is to maintain adequate navigation channel depths. Notches induce scour in the accumulated sediment behind the dikes, thereby restoring shallow aquatic habitat. In addition to their environmental function, dike notches can also maintain the flood flow conveyance capacity of the channel since they do not cause high accretion elevations that support permanent vegetation.

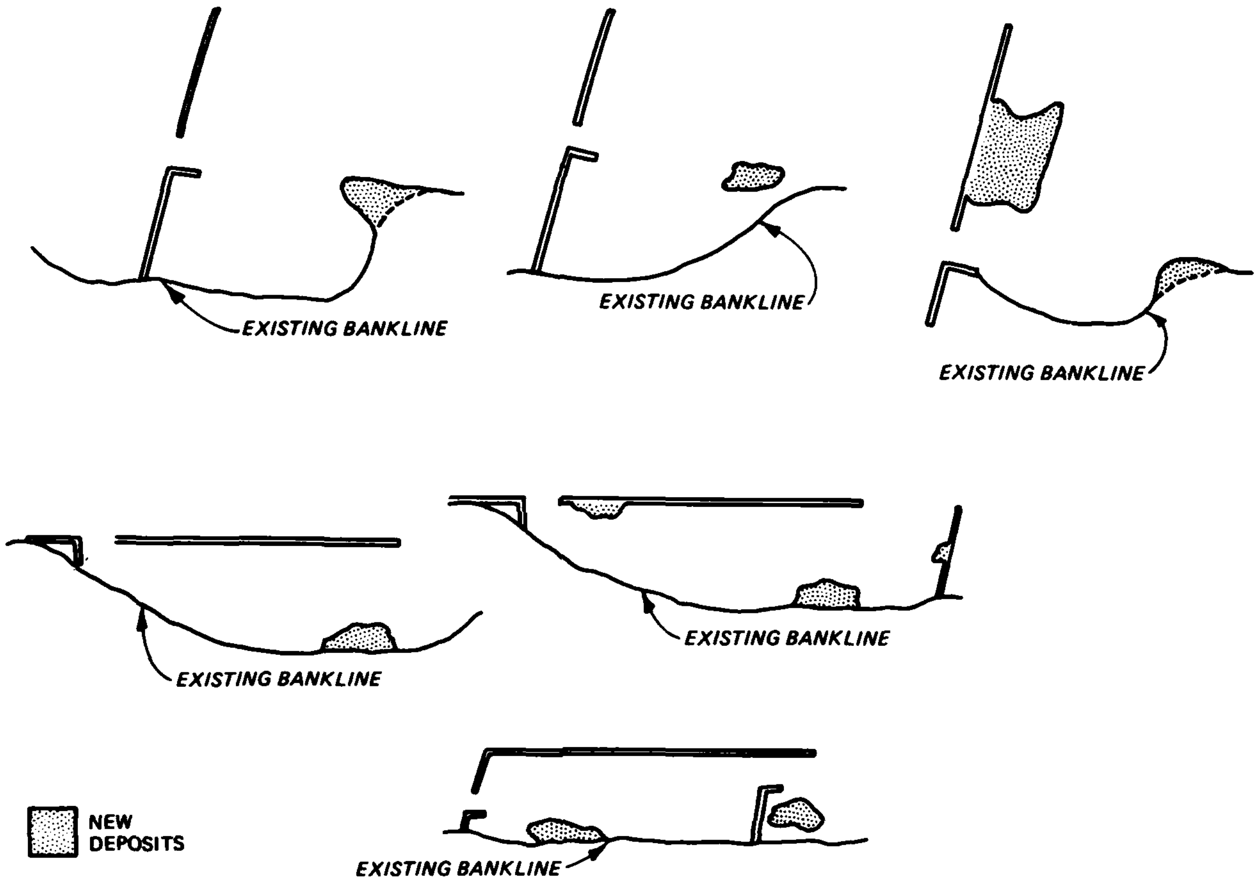



Figure 45. Sediment deposition patterns for notched dikes and crossing control structures; observed patterns from Missouri River. (Flow is from left to right in all cases.)

## Design and construction

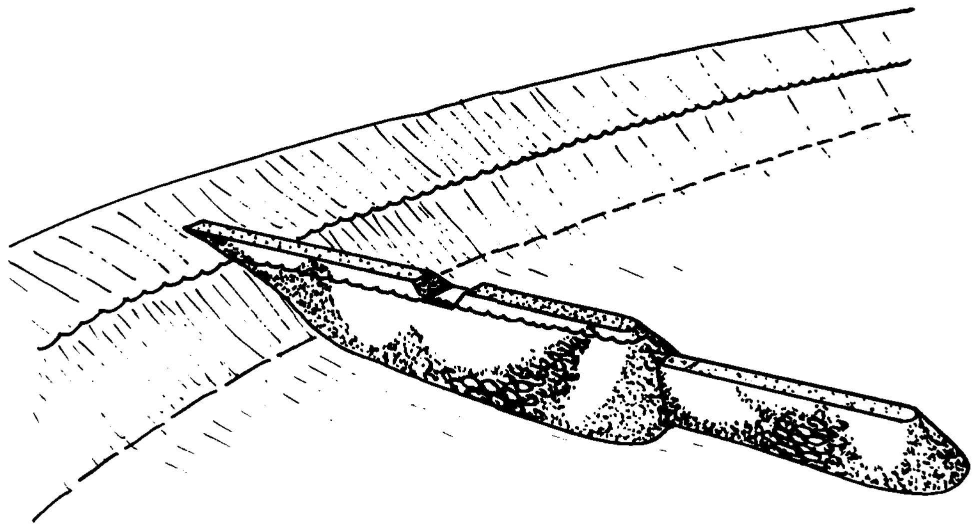
246. Design parameters for notched dikes include the location of the notch in the structure, the width of the notch, and the depth of the notch. The Missouri River notches are constructed as either triangular or trapezoidal sections 20 to 100 ft in width and are 3 to 12 ft lower than the rest of the structure (Burke and Robinson 1979). Typical sections for spur dike and revetment notches are shown in Figure 46. It should be noted that the Missouri River is a highly regulated river with more predictable flow and sediment transport characteristics than many alluvial rivers. Therefore the notch designs used on this stream may have adverse effects if applied to a stream with different characteristics.

247. Construction of the notches is accomplished entirely by barge-mounted draglines. Notches are normally located as close to the bank as possible without inducing bank erosion in order to provide a large area of potential shallow-water habitat. In some cases a new dike may be built with a gap 150-250 ft wide between the landward end of the dike and the bank. These "rootless" dikes have been used on the Missouri River with generally excellent results (Burke and Robinson 1979).

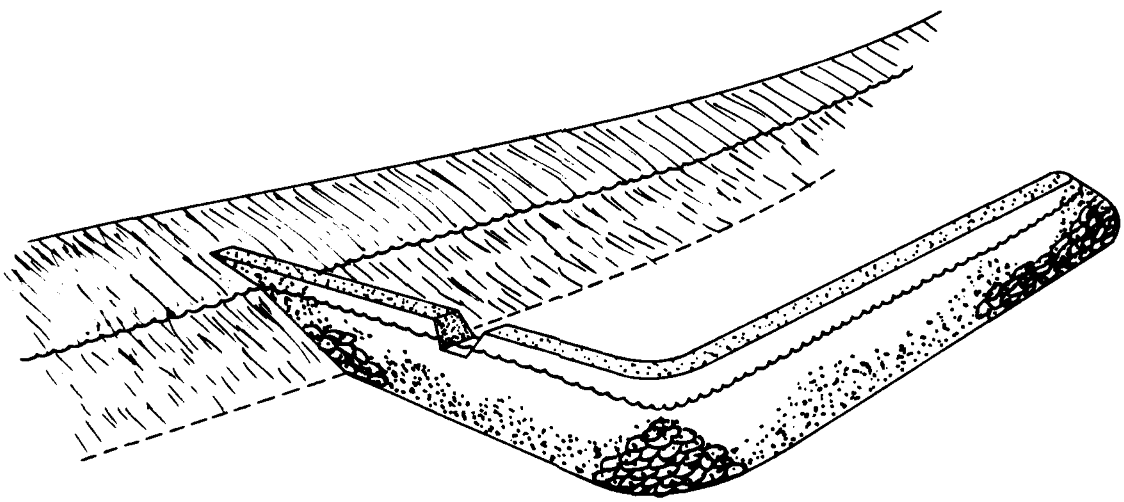
## Environmental considerations

248. Information regarding the environmental effects of dike notching is very limited at present. A cooperative effort (U. S. Army Engineer District, Omaha 1977) was initiated in 1975 between the U. S. Fish and Wildlife Service and others to determine the types of habitat created by notching dikes and the value of this habitat to fish along the Missouri River. Preliminary results of this study (Reynolds and Segelquist 1977) indicate:

> 1) that notched structures create types of habitat that are not provided by unnotched structures, 2) that certain species of fish are attracted to the habitats created by notched structures, and 3) that the most beneficial types of habitat created seem to be relatively large surface areas of quiet, slack water during medium to low river stages. Another observation is that habitats created by notched dikes are constantly changing. A tentative conclusion is that notches should be placed in structures so that high



a. Spur dike notch



b. Revetment notch

Figure 46. Missouri River dike notches

stage flows can sweep through backwater areas to scour and transport sediments; otherwise, backwater areas may become filled with sediment and eventually become part of the permanent floodplain.

249. In addition to notched dikes and rootless dikes, lower crest elevations and notches in chute closure structures have been used to reduce sediment accretion rates and develop aquatic habitat (Burke and Robinson 1979).

## Recent Developments

### EWQOS field studies

250. Field studies being conducted as part of the EWQOS program are designed to provide data concerning the value of dikes to the riverine aquatic community. Specifically, the EWQOS waterway field studies seek to:

- a. Define and map riverine habitats for specific study reaches.
- b. Describe physiochemical characteristics of water and sediments.
- c. Assemble biological data regarding species composition, diversity, abundance, and production.

These studies will provide data to be used in developing environmental quality guidelines for design and construction.

### Hydraulic model studies

251. The WES Hydraulics Laboratory is currently conducting a series of model investigations as part of a study regarding basic dike design parameters. Dike angle, height, profile slope, and spacing will be investigated to determine basic design guidance for achieving the optimum degree of scour in the navigation channel. Any recommendations regarding guidance for environmental quality must be compatible with results concerning the basic hydraulic design parameters.

## Summary

252. Dikes are longitudinal or transverse structures placed in

navigation channels to concentrate the flow into a narrower, deeper channel. Dikes are also used in conjunction with bank protection to maintain the channel in a desirable alignment and to protect eroding banks and levees. Most dikes are currently made of quarry-run stone.

253. Several dike shapes and alignments are used individually and in combination to achieve desired objectives. Terminology used to describe various dike types varies from region to region.

254. Little formal design guidance is available for dikes. Several sources have documented the need for environmental design guidance for dikes. Placement of dike fields and design of individual dikes is largely dependent on the experience and judgment of individual designers. Significant differences and similarities exist between dike designs used by various CE field offices. Design parameters for spur dikes include channel alignment, dike length, height, profile slope, crest width, angle with flow, side and end slopes, stone size, and spacing between dikes.

255. Dikes are usually constructed by placing stone from barges or by end-dumping from trucks. Dikes are keyed into the bank with a stone-filled trench. Bank clearing, grubbing, and grading are required for construction of the key trench. Dikes are sometimes constructed in stages over several seasons.

256. Environmental impacts associated with dike construction are minor and temporary. Dike structures and dike fields provide valuable habitat for fish and macroinvertebrates. The major environmental impact associated with dikes are long-term changes in the riverine habitat. Sediment accretion in the dike field can eventually lead to loss of valuable backwater areas, and an overall reduction in aquatic habitat area and habitat diversity. When dikes are used in conjunction with bank protection to maintain the channel in a desirable alignment, the channel is no longer free to meander and create new backwater areas to replace old ones as they are lost due to sedimentation.

257. Most dikes in the United States are found in either the Missouri or Mississippi Rivers. Marked reductions in water surface area have been observed since dikes have been constructed on the Missouri River. The effect of dikes constructed on the Upper Mississippi River

has been obscured by the subsequent construction of locks and dams. Similar changes have not occurred on the Middle Mississippi River. The effect of dikes on the water surface area of the Lower Mississippi River has not been quantified.

258. Notches have been cut in dikes on the Missouri and Middle Mississippi Rivers to reduce the rate of sediment accretion and restore aquatic habitat. The notches have not affected the navigation channel alignment or depths. A preliminary study on the effectiveness of the Missouri River dike notches in restoring and maintaining desirable aquatic habitat gave positive results. Design parameters for dike notches include the location of the notch in the structure, and the depth and width of the notch. Optimal values for these parameters vary considerably with site and stream characteristics, and a succesful design for one stream may not be desirable for a stream with different characteristics. Rootless dikes and low elevation dikes have also been used, and some notches have been placed in chute closure structures.

# PART V: STREAMBANK PROTECTION

## Introduction

259. Streambank protection refers to a variety of measures intended to control, reduce, or eliminate the processes of streambank erosion. This Part describes typical streambank protection projects and examines existing design and construction practices. The environmental impacts of streambank protection are discussed in general terms, and a brief review is presented of recently completed and ongoing research dealing with environmental aspects of streambank protection.

## Streambank Erosion

260. Streambank protection is used to counter the processes of streambank erosion. Although it is not the objective of this report to present a detailed discussion of streambank erosion, a few general principles will be mentioned:

a. Streambank erosion is a natural geomorphic process which may be accelerated or decelerated by the activities of man.

b. Variables in fluvial systems such as discharge, sediment discharge, grain size, depth of flow, channel width, channel slope, valley slope and sinuosity exhibit interrelationships that evidence the existence of a type of dynamic equilibrium. Changes in one or more of these variables, either man-induced or from natural causes, are accompanied by changes in one or more of the other variables. These changes represent the fluvial system's attempt to regain a state of equilibrium through the process of negative feedback (Chorley and Kennedy 1971).

c. Streambank erosion is influenced by factors pertaining both to the erosion site and to conditions at considerable distances from the site (Smith and Patrick 1979). Smith and Patrick present three mechanisms that produce streambank erosion: widening, deepening, and sinuosity changes. These mechanisms are interdependent and reflect the relationships between the variables in a fluvial system.

(1) Widening involves channel enlargement caused by either increased discharges, increased sediment discharge, or both.

(2) Deepening is the degradation or scouring of the channel bottom. The removal of lower bank material leads to upper bank sloughing and instability. The scouring of the channel bottom may be caused by increased discharges and/or changes in slope.

(3) Sinuosity change produces bank loss during change in stream meander configuration. The meandering process, however, generally builds up some banks as it erodes others.

261. A more exhaustive listing of the types of streambank erosion is given by the American Society of Civil Engineers (ASCE) Task Committee on Channel Stabilization Works and others (American Society of Civil Engineers 1965). These are summarized by Keown et al. (1977) as follows:

a. Attack at the toe of the underwater slope, leading to failure of the overlying bank. Most of these failures occur during a fall of river stage at the medium stage or lower.

b. Erosion of the soil along the bank caused by currents.

c. Sloughing of saturated cohesive banks incapable of free drainage, due to rapid drawdown.

d. Flow slides (liquefaction) in saturated silty and sandy soil.

e. Erosion of soil by seepage out of the bank at relatively low channel velocities.

f. Erosion of the upper bank and/or the river bottom due to wave action caused by wind or by passing boats.

## Purposes of Streambank Protection

### Erosion problems

262. Streambank protection is used to combat a variety of problems caused directly or indirectly by bank erosion. Among these problems are:

a. Loss of valuable land acreage, particularly along major rivers (Figure 47).

Figure 47. Streambank erosion (from Seibert (1968))

b. Failure or loss of structures built on or adjacent to eroding banks. Streambank protection is used routinely to protect bridge abutments, levees, floodwalls, roads and other structures (Figure 48).

c. Undesirable changes in channel alignment.

d. Shoaling in navigation or flood control channels.

e. Increased levels of turbidity and sediment concentration, which can be detrimental to aquatic organisms.

River training

263. A primary purpose of large-scale streambank protection projects on large, alluvial rivers is to halt or control the horizontal migration and widening of the channel. The channel is trained into and maintained in an alignment favorable for navigation and flood control and is constricted to produce depths suitable for navigation.

## Descriptions of Streambank Protection Methods

264. Streambank protection methods on alluvial rivers may be classified as either direct or indirect. Direct bank protection works

Figure 48. Streambank protection at bridge crossing (photo courtesy of the Soil Conservation Service)

are placed in contact with the bank to shield it from erosive forces. Paving is an example of direct bank protection. Indirect protection structures are used to deflect currents away from a critical area. Dikes are an example of an indirect structure.

265. Streambank protection methods may also be classified as permeable or impermeable, and structural or nonstructural. Pile dikes and fences are permeable, and concrete pavement is impermeable. Structural methods involve the placement of construction materials, and nonstructural bank protection generally refers to the planting or management of vegetation on the banks. Combinations of structural and nonstructural approaches to bank protection are common.

266. Detailed descriptions of some 38 streambank protection methods are presented by Keown et al. (1977). Many of these descriptions are accompanied by photographs or illustrations. Only very brief descriptions will be given in this report; the reader may refer to Keown et al. (1977) for more detail. The most widely used methods of bank protection are: (a) stone riprap, (b) concrete pavement, (c) articulated

concrete mattresses (ACM), (d) transverse dikes, (e) fences, (f) asphalt mix, (g) jacks, (h) vegetation, (i) gabions, (j) erosion-control matting, and (k) bulkheads. Table 3 provides a basis for unit cost comparison among these methods. Additional surveys of streambank protection methods are given by the American Society of Civil Engineers (1965) and Vanoni (1975).

Structural methods

267. Stone riprap. Riprap is probably the most versatile and widely used form of bank protection. Riprap consists of courses of quarried stone placed along the bank to be protected (Figure 49). Banks are prepared for placement of riprap by grading to a uniform design slope and by placing a bed of gravel, filter material, or a special fabric which allows seepage but prevents erosion of the bank material. The advantages of riprap over other bank protection methods include structural flexibility, ease of maintenance and repair, simple construction, and natural appearance. In addition, the use of riprap is compatible with the use of vegetation, as vegetation may grow through the spaces between the rocks in some situations. Riprap also may be recovered and reused (Keown et al. 1977).

268. Trench-fill revetment. The trench-fill revetment is commonly used to stabilize and realign channels (Figure 50). Banks are graded to the design slope, and a trench is excavated as deep as is economically feasible at the base of the bank and filled with riprap. Sometimes the upper slope is also covered with a blanket of riprap. Eventually the erosive action of the stream degrades the bank between the stream and the trench and the rock is "launched" down the slope and becomes the revetment (Keown et al. 1977).

269. Concrete pavement. Concrete pavement is an expensive method of bank protection, principally due to high construction costs. Maintenance costs are minimal and concrete pavements have a long design life. Pavements are therefore placed on banks where potential damage costs are high such as bridge abutments and along main-line levees in heavily populated or industrialized areas (Keown et al. 1977).

270. Articulated concrete mattresses. The technology of the

Table 3

1976 In-Place Cost Summary for Streambank Protection Methods*

| Streambank Protection Method | Cost/Unit dollars | Unit |
|---|---|---|
| Stone riprap | 3.50-30.00 | $yd^3$ |
| Concrete pavement | 90-125 | 100 $ft^2$ |
| Articulated concrete mattresses | 84 | 100 $ft^2$ |
| Transverse dikes: | | |
| Pile board | 40-55 | linear ft |
| Untreated clumps | 1500-2300 | clump (three 60-ft piles) |
| Stone | 40-65 | linear ft |
| Fences | 25-50** | linear ft |
| Asphalt mix (upper bank) | 60-80 | $yd^3$ |
| Kellner jack field | 16-47† | linear ft |
| Vegetation (grass) | 1.15-1.49<br>(500-650) | 100 $ft^2$<br>(acre) |
| Gabions | 40-47 | $yd^3$ |
| Erosion-control matting | 5.56-7.22<br>(0.50-0.65) | 100 $ft^2$<br>(yd2) |
| Bulkheads | 14-105 | linear ft |

* From Keown et al. (1977); cost figures supplied by CE Divisions and Districts.
** Range applies to new materials.
† Range applies to used and new materials.

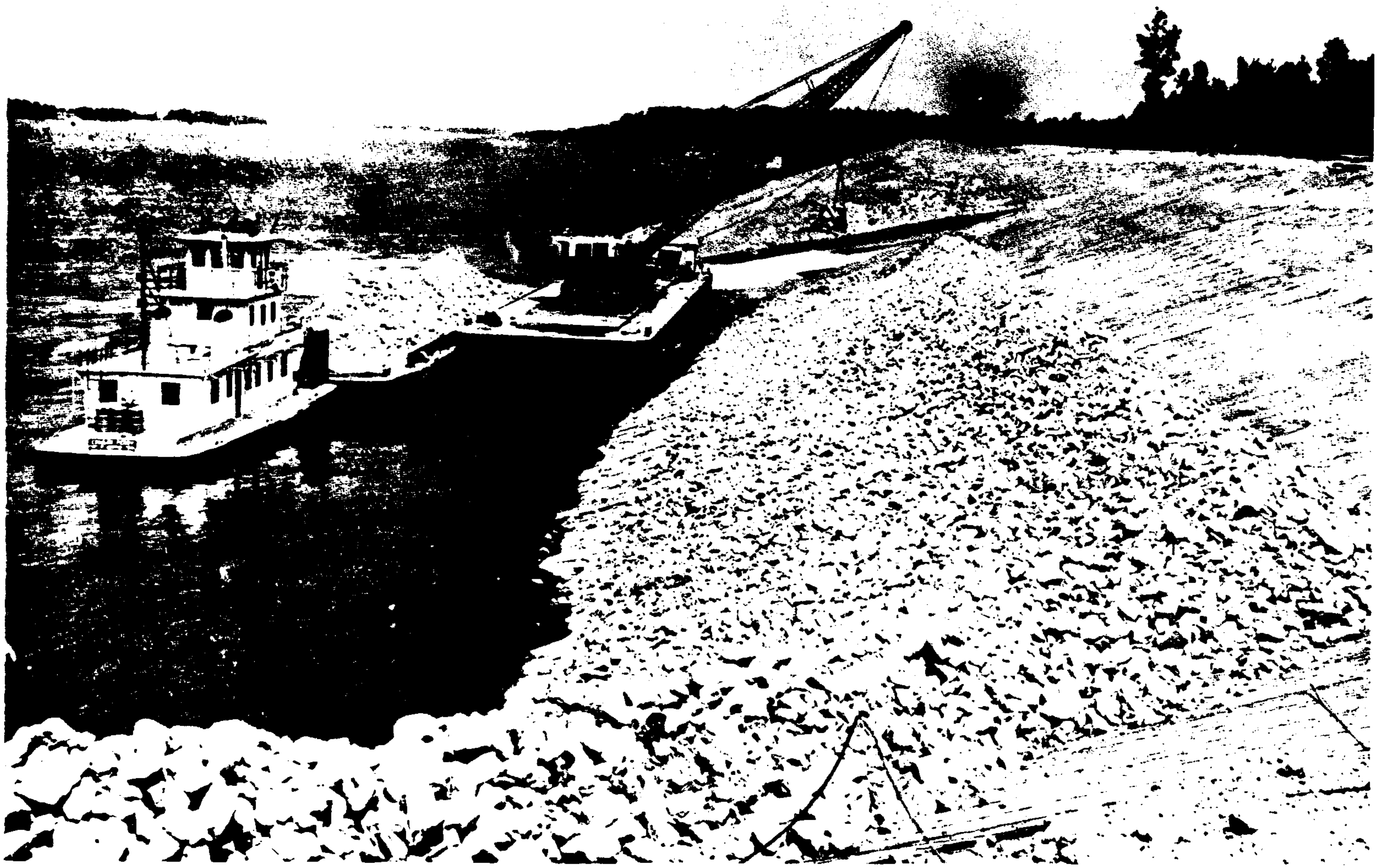


Figure 49. Riprap placement (from Keown et al. (1977))

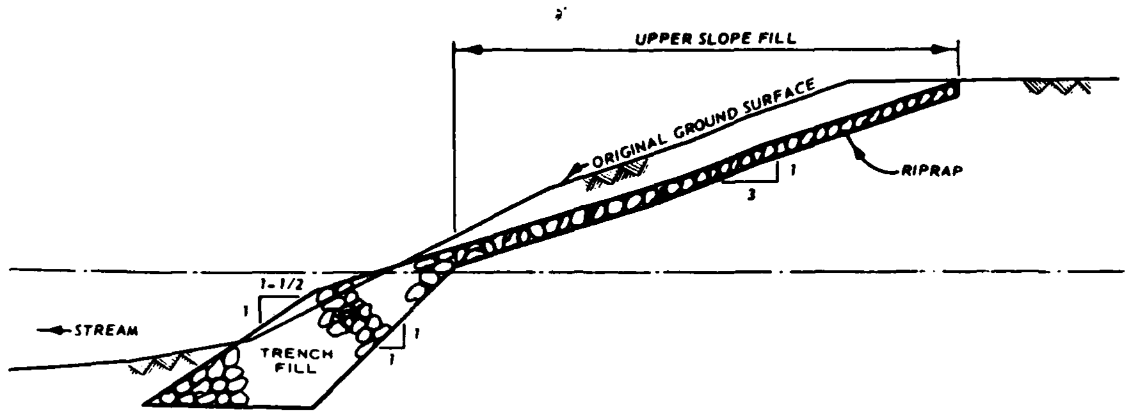



Figure 50. Trench-fill revetment (from Keown et al. (1977))

articulated concrete mattress has been developed to provide underwater revetment on the Lower Mississippi River. The ACM's are composed of slabs of concrete 3 ft, 10-1/4 in. long by 14 in. wide by 3 in. thick tied together with wire to form large mattresses. After the submerged bank is shaped to the design slope, the ACM's are placed in large units from a special barge (Figure 51). ACM placing operations are confined to periods of low water. ACM's are normally placed from 6 ft above mean low water to a point 50 ft past the thalweg. ACM's are ideally suited to an environment of high velocity and sediment loads because of their flexibility and weight. However, because of the specialized construction equipment required, the use of ACM's outside of the Lower Mississippi Valley is normally uneconomical (Keown et al. 1977).

271. Transverse dikes. Transverse dikes are discussed in Part IV of this report. Dikes protect the bank by deflecting the current, and banks opposite dike fields often must be revetted. Dikes may be relatively impermeable stone structures or simply rows of pilings. New dikes on the Lower Mississippi River are all stone dikes.

272. Fences. Fences are often used as stopgap measures on small, low-gradient streams to prevent bank sloughing or to allow time for the establishment of vegetation (Figure 52). However, some fences give several years of service. Fences are built either parallel to the bank or at an angle to promote sediment deposition. Fences may be angled to

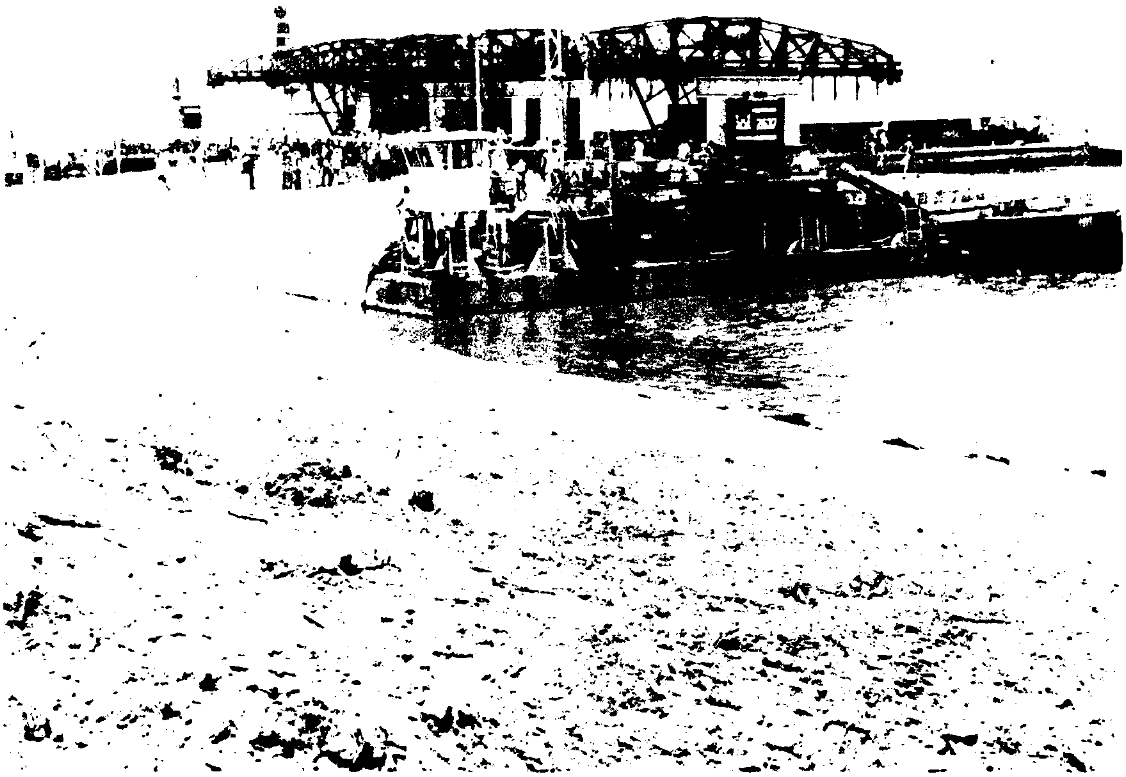


Figure 51. Articulated concrete mattress sinking operation (Launching barge is at left; from Keown et al. (1977))

either trap or deflect floating debris. Fences can be built of wire, treated wood, concrete posts, used rails, pipe or steel beams. Although fences are not considered one of the most effective bank protection methods, they are widely used because of the ease of construction and the wide availability of suitable materials compared to other methods of bank protection (Keown et al. 1977).

273. Asphalt mix. The use of asphalt blocks and mattresses for underwater bank protection has been tried, but has proven largely ineffective. The use of uncompacted bulk asphalt mix on upper banks has proved successful (Keown et al. 1977).

274. Jacks. Although jacks may have one of several configurations, the most common is three linear members bolted together at their midpoint so that each member is perpendicular to the other two

Figure 52. Wooden fence as streambank protection (photo courtesy of the Soil Conservation Service)

(Figure 53). Jacks are usually arranged in a field and laced together with cable. Jacks can be made of a variety of materials--wood, metal, or concrete--and are easy to assemble and place. Jack fields slow the current velocity next to the bank, encouraging deposition. They also deflect the thalweg away from the bank. Jacks are usually not aesthetically harmonious with the riparian landscape, but they may be partially overgrown with vegetation in time (Keown et al. 1977).

275. Gabions. Gabions are wire mesh baskets filled with rock. The wire mesh may be galvanized or coated with polyvinyl chloride (PVC) to deter corrosion. Gabion works are constructed by placing a support apron, also of gabions, and stacking gabions in steplike fashion on top of the apron (Figure 54). Baskets are placed and laced together with wire before they are filled with stone (Keown et al. 1977).

276. Gabions offer several advantages. The voids allow for bank

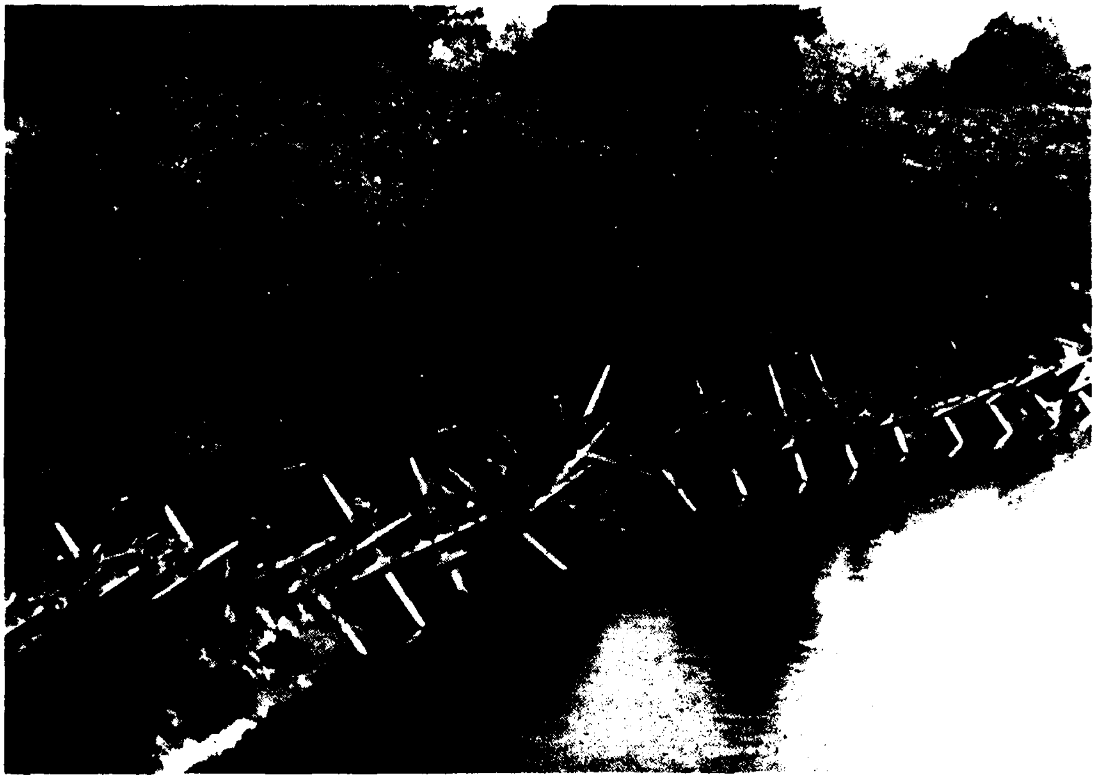


Figure 53. Kellner jacks (Jacks may be partially overgrown with vegetation and require little bank preparation before installation; photo courtesy of the Soil Conservation Service)

Figure 54. Gabions used to stabilize a small stream channel (Gabions placed in the bed form a series of small steps in bed elevation and also stabilize the base of the side slope; from Linder (1976))

drainage, which eliminates failures due to excessive hydrostatic pressure. Some of the voids eventually fill with sediment and vegetation appears. Gabion works are flexible and can be placed in a curving channel. Since they are flexible, shifts in the underlying bank are not always disastrous. Gabions may be placed at a steeper slope than riprap, and the required thickness of a gabion cover is one-half to one-third that of riprap at the same location. Construction of gabion works generally requires less site preparation and less skilled labor than construction of rigid linings. Drawbacks associated with gabions include basket failure due to vandalism, corrosion, or the impact of heavy floating debris. Gabion projects tend to require more unskilled labor than rigid linings or riprap (Burroughs 1979).

277. Erosion-control matting. Erosion-control matting is generally a weblike fabric which allows vegetation to grow through. It is installed on an eroding bank to provide short-term protection while vegetation becomes established. A variety of mats are commercially available, many of which are biodegradable. Matting is generally installed by hand and secured with stakes (Keown et al. 1977).

278. Bulkheads. Bulkheads provide a stable, vertical land-water interface. As such, they are frequently used around marinas and waterfronts. Bulkheads may be built of timber, concrete, or prefabricated asbestos or metal sheets (Keown et al. 1977).

279. Other methods. Keown et al. (1977) list several other methods of bank protection which are used sparingly. Among them are old automobile bodies, used tire mattresses, concrete blocks, and sack revetments. Methods that are now obsolete include large willow mattresses, logs and cables, and stone-filled timber cribs.

## Vegetation

280. Although several investigators have experimented with vegetation as a streambank protection technique (Allen 1978), the use of vegetation has been largely restricted to areas above the mean high-water line, in backwater areas, and in channels which are only occasionally used as floodways. Historically, grasses that are not tolerant to prolonged inundation in flowing water have been used for bank protection

(Keown et al. 1977, U. S. Department of Agriculture, Soil Conservation Service 1977, Parsons 1963). Recently some investigators have experimented with native species that have varying degrees of flood tolerance and with bank protection methods that combine structure and vegetation.

281. Parsons (1963) described three ways that vegetation reduces bank erosion: (a) vegetation protects a bank by reducing current velocity next to the bank (Figure 55 shows velocity profiles measured in a bare channel and a channel lined with bermuda grass.); (b) vegetation also serves to buffer the bank material against the forces of transported solid objects such as ice, logs, and bed material; and (c) shrub-type plants may act as skid surfaces for the transported materials as they are deflected by the banks.

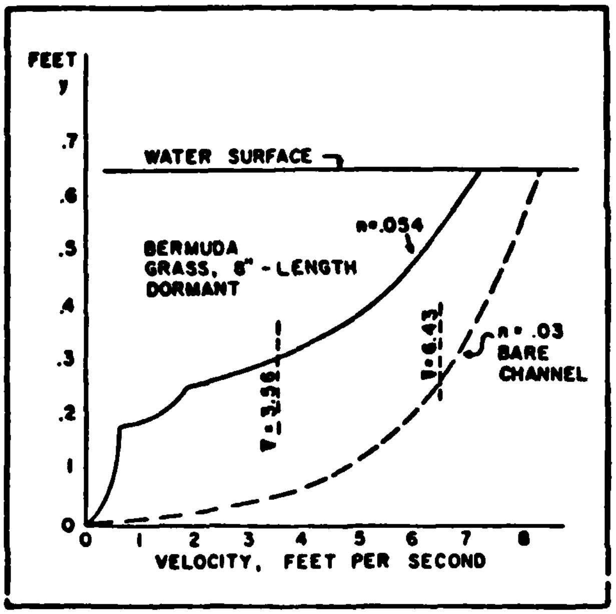



Figure 55. Influence of vegetation on variation of velocity with depth below water surface (after Parsons (1963))

282. Allen (1978) presents a brief literature review on the use of plants to control streambank erosion. The mechanisms of erosion control by vegetation are identified as follows:

> Bailey and Copeland (1961) pointed out the value of vegetation per se in controlling erosion through its attributes of water interception, transpiration, energy dissipation, soil stabilization, and infiltration enhancement. They stated that vegetation contributes to soil stability by binding the soil into stable aggregates that resist transport by flowing water. Gray (1977) related the effects of vegetation to stress-strength relationships in the soil, particularly on slopes. He stated that vegetation helps to control terrestrial slope erosion and mass wasting by the following processes: root reinforcement of the soil, restraint and filtering of soil particles, restraint of soil masses on slopes by soil arching effects, interception of precipitation, and depletion of soil water (Allen 1978).

283. Experiments have demonstrated that the ability of grass to reduce erosion is directly related to the length, width, and density of the blade, the areal density of the grass, and the depth of the root system. Parsons (1963) presented a tabulation of equivalent stone sizes for various stands of bermuda grass (Table 4).

Table 4

Equivalent Stone Sizes for Bermuda Grass Linings

| Condition of Bermuda Grass | Allowable Shear Stress lb/sq ft | Equivalent Stone Diameter in. |
|---|---|---|
| Fair stand, short,* dormant | 0.9 | 2 |
| Good stand, kept short, dormant | 1.1 | 2 |
| Good stand, long,** dormant | 2.8 | 5.5 |
| Excellent stand, kept short, green | 2.7 | 5.5 |
| Good stand, long, green | 3.2 | 6.5 |

* Less than 5 in. high.
** Greater than 8 in. high.

284. Banks protected by vegetation (such as grassed channels) require frequent inspection and prompt maintenance to prevent bank failure due to gullying. Maintenance is also required when vegetation

is lost or weakened by drought or disease.

## Existing Practices for Design and Construction of Streambank Protection

### Design of streambank protection

285. Existing streambank protection design practice may be characterized by (a) consideration of local eroding reaches rather than the entire stream basin, and (b) the use of experience and judgment. This approach is due to the wide range of hydraulic and erosional conditions encountered, as well as economic variables such as the cost and availability of materials, equipment, and manpower (Keown et al. 1977). General design guidance for various types of streambank protection has not been formulated. More design guidance is available for riprap than other methods (Maynord 1978, U. S. Army, Office of the Chief of Engineers 1970 and 1971a), yet there is no mention of environmental considerations in this guidance. Some information is available on flood-tolerant plants (U. S. Army, Office of the Chief of Engineers 1980c), but this information does not deal directly with the use of vegetation for streambank protection.

286. Although a variety of experiments have been conducted to determine the advantages of various bank protection methods, no specific guidelines have resulted that would help a design engineer develop alternate protection methods for a particular project. The current design procedure for many types of bank protection is based on experience and subjective judgment (Keown et al. 1977). A few analytical tools are available for limited use.

### Construction of streambank protection

287. Construction of structural streambank protection usually necessitates the removal of riparian vegetation (clearing and grubbing) and grading the bank to a design slope using heavy equipment. Design slopes are usually created by building up the toe of the bank and pulling back the top or by excavation of the top with no fill at the toe. Jacks and fences may be installed without such extensive site

preparation. The use of floating plant to install revetments on large streams reduces construction impacts since less clearing of riparian vegetation is required.

Vegetation

288. Design of vegetative bank protection usually involves site preparation and selection of the species of grasses or woody plants to be used. Gray (1977) identified 35 degrees as the maximum angle for establishment of vegetation on most banks, but this varies with soil type. A narrow band of riprap or some other type of structural protection will probably be needed at the toe of the slope to prevent undercutting (Allen 1978). Factors that affect species selection include the local climate, soil, and streambank conditions. The amount of time required for a good stand to become established is also a major consideration (Keown et al. 1977). Guidance on selection of flood-tolerant plant species is given in U. S. Army, Office of the Chief of Engineers (1980b).

289. Installation of the vegetative cover is dependent on the species selected. Keown et al. (1977) explain that the top soil of an area to be planted with grass is usually stripped because it provides a fertile bed that enhances weed growth. Conversely, Logan et al. (1979) prescribe spreading topsoil to a depth of 4 in. over sites to be planted with native species. Grasses may be planted by sodding, sprigging, or by the mechanical broadcasting of mixtures of seed, mulch, and fertilizer. Woody plants generally must be planted from nursery stock and have a much higher initial cost than grasses. However, in some cases woody plants or a combination of woody plants and grasses provide better bank protection than grasses alone (Keown et al. 1977).

## Environmental Considerations

290. The technical literature yields relatively little information on the environmental impacts of streambank protection. Much of the information in the literature is qualitative and does not present any field data. In the absence of quantitative information, insight into

the environmental effects of bank stabilization may be gained by studying the physical and biological characteristics of unaltered streams. The effects of bank protection may then be estimated or inferred.

Site-specific factors

291. Environmental data from a bank protection project, or any other type of modified channel, must be evaluated in light of local conditions. Most streams with protected banks have also been modified in a number of other ways, so the impacts of bank protection are difficult to isolate. Streambank protection is often used in conjunction with channel enlargement and alignment, downstream from dams, and on the riverside of levees. The bank protection may even be necessitated by other types of modification. For example, a straightened channel may be unstable without bank protection. The nature of the native riparian community and its sensitivity to change will vary considerably from one geographical region to another. Site-specific factors must therefore always be considered.

292. The following discussion of impacts attempts to integrate observations made in several different systems. Although no system will exhibit responses identical to another, this presentation is useful for identifying potential consequences of bank protection.

Physical impacts

293. The physical effects of streambank protection are best understood when the fluvial system is considered as a whole. Numerous investigators have observed general relationships among the hydrologic-geomorphic variables in fluvial systems. These relationships are given by Smith and Patrick (1979) as follows:

a. Depth of flow $Y$ is directly proportional to water discharge $Q$.

b. Channel width $W$ is directly proportional to both $Q$ and sediment discharge $Q_s$.

c. Channel shape, expressed as width to depth ratio $W/Y$, is directly related to $Q_s$.

d. Channel slope $S$ is inversely proportional to $Q$ and directly proportional to $Q_s$ and median grain size.

e. Sinuosity is directly proportional to valley slope and inversely proportional to $Q_s$ .

f. Transport of bed material is directly related to stream power* and concentration of fine material and inversely related to the median fall diameter of the bed material.

The exact relationships vary considerably from site to site and therefore cannot normally be used as predictive tools. These relationships are given here to support the concept of treating the entire channel as a system.

294. Streambank protection directly influences at least two of the above variables, width and sediment discharge, which in turn influence the others. Extensive bank protection controls the channel width. A stream with unprotected banks may alter its width in response to changes in discharge or sediment discharge, but a stream with stabilized banks must compensate for changes in discharge or sediment discharge by changing other variables in the fluvial system. Sediment discharge is reduced when eroding banks are stabilized. If the decrease in sediment discharge is significant, the fluvial system may adjust by eroding and degrading the channel bed.

295. The examples given above are simplified. A real fluvial system will usually exhibit influences of other types of channel modifications in addition to streambank protection (i.e., levees, channel alignment, or upstream impoundments) which are as strong as or stronger than the influences of bank protection. Processes at work in the drainage basin can also strongly affect the hydrograph or sediment discharge.

296. Large-scale bank protection works (dikes and revetments) on navigable streams in conjunction with other types of channel modifications have caused changes in stream length, width, and water surface area. These changes in channel morphology sometimes result in a reduction in the total amount of aquatic habitat and a loss of valuable shallow-water areas.

297. Funk and Robinson (1974) found that the water surface area

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* Stream power = specific weight of water × hydraulic radius × slope × velocity.

of the lower 500 miles of the Missouri River decreased by 60,832 acres, or by 50 percent, between 1879 and 1972. The reach also became 45.6 miles shorter. These changes occurred as the river was aligned with dikes and revetments. Stabilization of banks with revetment and sediment deposition between dikes has made the river narrower and deeper.

298. In a natural alluvial river, side channels are formed and destroyed by the processes of meandering and deposition. As old side channels are obliterated by deposition, new ones are formed by river channel migration. In a stabilized river the processes of migration are retarded or eliminated so that new side channels are not formed to replace old ones as they are filled. Side channels provide habitats important to the riverine fish and wildlife communities. They also represent a recreational and aesthetic resource. The loss of side channels and shallow-water habitats is a major impact of some large-scale bank protection projects (Johnson et al. 1974).

299. Although dikes and revetments have led to some losses of aquatic habitat, there is some evidence to suggest that they provide additional habitat for benthic macroinvertebrates (Johnson et al. 1974, Mathis et al. 1981). The overall effect of this trade-off of habitats has yet to be quantified. The long-term effects of channel stabilization may be much different than the short-term effects, since, in many cases, sediment deposition will sometimes eventually cover dikes, eliminating them as aquatic habitat.

300. Sediment discharge. Construction of structural bank protection works usually increases downstream sediment discharge and turbidity temporarily during the construction period. After bank protection is installed, however, it may reduce the sediment discharge by stabilizing eroding banks. Miller and Borland (1963) reported a substantial decrease in sediment discharge in two Wyoming creeks following intiation of streambank protection works. These reductions were achieved despite increasing water discharge during the same period due to increasing discharge of irrigation return water into the creeks.

301. Temperature and light conditions. Changes in stream light conditions and water temperature regimes associated with streambank

protection may be caused by removal of streambank vegetation for construction and maintenance of bank protection works and by changes in turbidity and suspended solids concentrations. Removal of streambank vegetation decreases shade over the stream and increases insolation. Increased insolation raises water temperatures. Changing light conditions may increase photosynthetic activity, leading to algal blooms and/or invasion of the stream channel by rooted vegetation during low-flows periods (Gorman and Karr 1978). Increased turbidity and suspended sediment concentrations reduce the light penetration in water and absorb energy from sunlight, leading to increased water temperature.

Chemical impacts

302. Practically no information is available regarding the influence of bank protection on chemical water quality. Chemical impacts of streambank protection projects are directly related to physical impacts such as changes in sediment discharge, light conditions, water temperature or changes in hydraulic variables. Sediment serves as a vehicle for the transport of chemical substances in streams. Water temperature and photosynthetic activity exert influences on dissolved oxygen and nutrient concentrations.

303. Observed effects of streambank protection on chemical water quality have varied considerably from site to site. Obviously, this variation is due to the unique features of each situation. Two studies are cited below as examples.

304. In a study of Iowa streams where short reaches of bank had been stabilized for highway protection, Witten and Bulkley (1975) found that the bank protection structures had no significant influence on water temperature or turbidity. Bank protection structures in the study areas included riprap revetments, fences, and permeable and impermeable dikes.

305. Bradt and Wieland (1978) reported the effects of installing gabions on the banks of a modified Pennsylvania trout stream to restore fish habitat. The gabions deepened and narrowed the stream channel, resulting in cooler summer temperatures. Increases were also observed in dissolved oxygen concentrations, total alkalinity, and specific

conductance, but these changes were at least partially due to other influences.

Additional information

306. Stern and Stern give an annotated bibliography (Stern and Stern 1980a) and a synthesis (Stern and Stern 1980b) of some 200 literature references on the impacts of bank stabilization on the physical and chemical dynamics of small streams. ("Small streams" refers to those streams that can be waded or used only by small pleasure boats.) The effects of bank stabilization on 10 physical and chemical characteristics of streams were examined. These 10 characteristics were: (a) depth and stage, (b) water surface area of channel and floodplain, (c) channel configuration, (d) current velocity, (e) water temperature, (f) suspended solids, (g) bed materials, including bed load, (h) dissolved substances, (i) light transmissivity, and (j) flow variability.

Biological impacts

307. Biological changes that accompany streambank protection generally are caused by physical and chemical changes directly attributable to streambank protection and associated channel modifications. Biological impacts may be loosely categorized as aquatic or terrestrial. Terrestrial impacts frequently involve losses of riparian vegetation and land-water interface. Aquatic impacts frequently involve losses and gains of habitat and habitat diversity, and creation of stable substrate.

308. Riparian vegetation is particularly valuable to fish and wildlife. The edge effect of the land-water interface produces a diversity of habitats which in turn foster abundant and diverse animal communities. The numbers and kinds of animal species occupying the riparian vegetation-water interface is usually much larger than that occupying nearby open water and land. Terrestrial insects that fall into the stream from overhanging branches are a food source for the aquatic community. Leaves and twigs that fall into streams are also an important food source of some aquatic organisms, particularly for low-order streams. Riparian vegetation with low, overhanging branches and exposed root structure provides essential habitat components for fish

and other aquatic organisms. Submerged roots and brush provide a stable surface for the attachment of epifaunal organisms and shelter from predators and strong currents for fish. Because of the "edge effect" of the vegetation-water interface and because of the linear distribution of riparian vegetation, the corridor of riparian vegetation is much more valuable to many wildlife species than an equal acreage of similar vegetation in a block. Furthermore, since many floodplains are cleared for agricultural or urban uses, the thin strip of riparian forest provides a very scarce type of habitat (U. S. Army Engineer District, Sacramento 1980).

309. As noted above, extensive streambank protection works can cause a diminution of channel migration (Johnson et al. 1974, Johnson, Burgess, and Keammerer 1976). Channel migration is important biologically because it creates a diversity of plant and animal habitats. The elevational differences of a point bar from the water's edge landward cause a gradation in plant species to develop. An early successful stage, often an annual plant species, will develop near the water. As the bar builds and becomes less subject to inundation, later successional stages will develop. Johnson, Burgess, and Keammerer (1976) present data on floodplain tree populations for a reach of the Missouri River affected by flood control reservoirs and bank stabilization. The reduction in flooding and channel migration that followed these modifications seemed to be leading to long-term changes in regional forest composition and structure. Figure 56 depicts the distribution of tree species on a portion of the Mississippi River floodplain, which illustrates the gradation of plant habitats. Stabilization of riverbanks, particularly when coupled with upstream flood control, reduces the rate of formation of new point bars. Older riparian areas gradually become populated by progressively later successional stages of plants. Thus, without constant change in the bank configuration, tree species composition may change and diversity in floodplain forests may be reduced.

310. On the other hand, Klein et al. (1975) found that revetments along the Upper Mississippi and Lower Illinois Rivers had a minimal effect on vegetation, probably because overbank flooding was allowed to

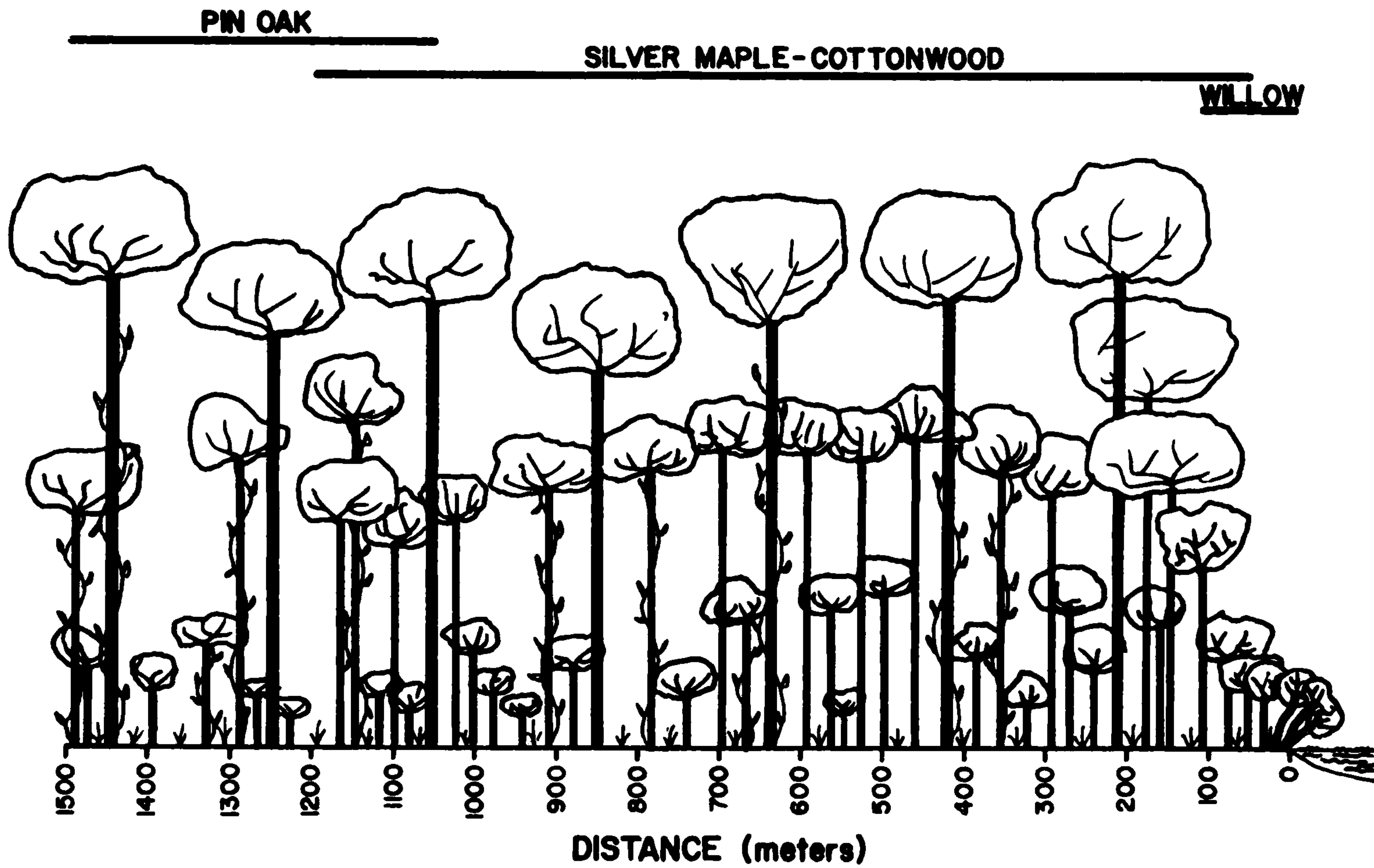



Figure 56. Representative distribution of tree species in a floodplain forest community (from Johnson et al. (1974))

continue and the overall effect of modification on channel morphology had been less drastic than on the Missouri River. Klein *et al.* (1975) findings are quoted below:

> Impacts of revetment on vegetation are minimal. Revetment is usually placed along steep banks to retard further erosion. By stabilizing the bank, they [revetments] keep land loss to erosion at a minimum and, therefore, this land is available for plant life. In the areas adjacent to revetments that were forested, typical silver maple-cottonwood stands were found. This was expected, since the revetments are low (usually about 1 m) and thus provide little flood protection. The plants which grew on the revetted slopes are mostly widely distributed species and the increase in habitat for these plants is insignificant.

311. Johnson et al. (1974) found that riparian plant community composition along the Middle Mississippi River was probably affected by levees, dikes, and revetments. Changes in flood patterns caused by levees have led to the demise of several species less tolerant of flooding.

312. Construction of bank protection works may result in considerable initial loss of vegetation since the sites must be prepared by clearing, grubbing, and grading to a design slope before placement of continuous-type bank protection. Clearing is also necessary for the contractor's work areas. Bank protection works may or may not revegetate after construction, depending on maintenance procedures and the ability of native plants to colonize the modified bank. Bank protection adjacent to levees is frequently kept clear of vegetation to facilitate levee inspection (Mifkovic and Petersen 1975).

313. The importance of riparian vegetation to birds was studied by the U. S. Fish and Wildlife Service at a selected location along the Sacramento River (Hehnke and Stone 1978). The study site consisted of eight rectangular plots of approximately equal area on either side of a short reach of the river. Four of the plots lay inside the levee and along the river. Two of these plots contained riparian vegetation and no bank protection, and the other two had only grass or shrubs and riprap revetments. The remaining four plots were rectangles of agricultural

land at right angles to the bankside plots. Both sides of the river were leveed, and similar agricultural vegetation was on the landside of both levees.

314. The results of this study are summarized in Figure 57. Significantly more birds and bird species were observed in the natural riparian areas and adjacent agricultural lands than in the riprap habitat and its adjacent agricultural lands. The riparian vegetation and its support capacity influenced bird populations of adjacent agricultural lands to a depth of at least one-fourth mile.

315. Emergency channel modifications on the White River in Vermont involved removal of riparian vegetation along modified reaches. Studies by Dodge et al. (1976) during the two years following modification revealed that songbirds were more abundant and diverse in natural control reaches than in modified reaches. Groups of birds categorized by feeding strategy were affected differently: species dependent on vegetation for food and cover were adversely affected by clearing.

316. Natural streambanks provide habitat for a number of mammal species. Cut banks are useful for burrowing species such as muskrats. Both large and small mammals may use the riparian zone for a variety of purposes. Populations of small mammals were affected by removal of riparian vegetation for channel modification of the White River in Vermont (Dodge et al. 1976). Some species were eliminated or greatly reduced in cleared reaches. Large mammals with a larger home range are probably less affected by removal of riparian vegetation.

317. Benthic macroinvertebrates are an important food source for some species of fish. Benthic organisms tend to be more abundant and diverse in a stable, sheltered substrate than an unstable, shifting substrate (Hynes 1970). Preliminary observations on the Middle Mississippi River indicated that riprap revetment may provide habitat for a diverse assemblage of aquatic organisms by stabilizing the river's banks (Johnson et al. 1974).

318. Preliminary sampling of benthic populations of several types of habitat on the Lower Mississippi River indicated that dike structures and possibly revetments are productive habitats for benthic

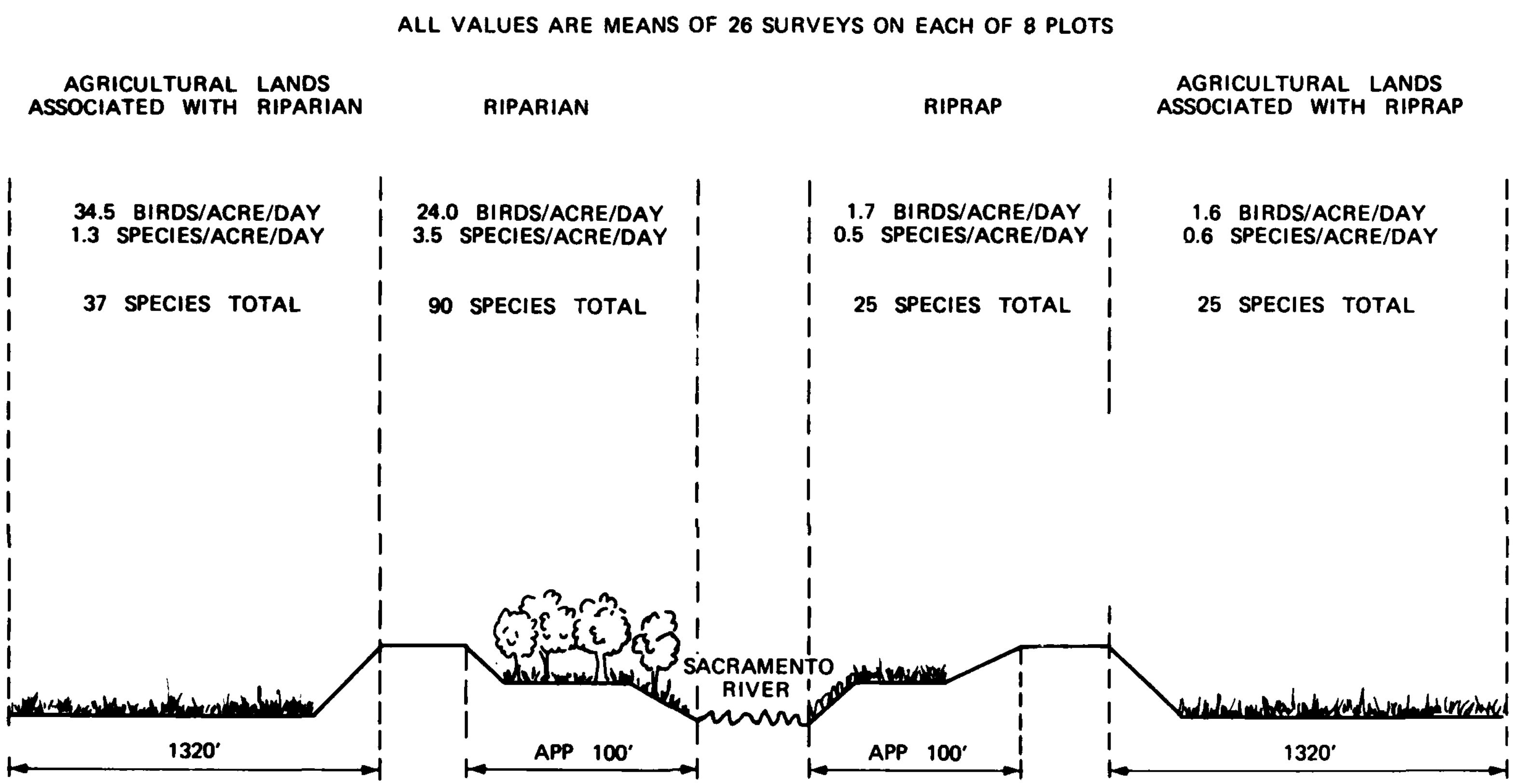



Figure 57. Influence of riprap streambank protection on bird population, Sacramento River; summary of one year's data on eight different plots from Sacramento River near Knight's Landing, Calif.

macroinvertebrates (Mathis et al. 1981). A summary of this work is found in Table 5. Dike structures were by far the most productive habitat type for benthic macroinvertebrates. The dike structures in the study area were made of quarry-run limestone riprap similar to riprap used for revetment on many smaller streams, with the exception that quarry-run stone has a wider size gradation. The results of sampling revetted banks were highly inconclusive because the sampling procedure used was inadequate for obtaining samples from the ACM revetment. However, field evaluations during and after the sampling effort suggest that the ACM is a fairly productive benthic macroinvertebrate habitat. Results of this study are not definitive since sampling was confined to a one-month period. The study was designed as a pilot to develop sampling techniques and experimental designs for a subsequent long-term field study.

319. Winger et al. (1976) found that riprap used for streambank stabilization in modified reaches of Crow Creek, Tenn. and Ala., provided cover for fish, particularly game fish, and provided a stable substrate for epiphyton and benthic macroinvertebrates. The use of riprap on unstable banks was recommended as an environmentally sound technique for similar projects.

320. Witten and Bulkley (1975) sampled invertebrates from bank stabilization structures near highway bridges in several small Iowa streams. Rock structures (revetments and impermeable jetties) fostered the growth of some invertebrates (primarily mayflies and caddisflies). No organisms were found on steel structures (permeable jetties and retards (fences)).

321. Little information is available on the impact of streambank protection on fisheries. Since bank protection works usually are part of projects which include other types of channel modifications, it is difficult to isolate the effects of bank protection. Fish may be affected by streambank protection indirectly since bank protection sometimes causes changes in light conditions, water quality, or populations of lower organisms. In general, fish populations are probably adversely affected by losses of cover and habitat diversity which accompany some

Table 5

Summary of Benthic Macroinvertebrate Data Collected from Nine Aquatic Habitats, Lower Mississippi River, June 1978*

| Habitat Type | Total Organisms Collected | Avg Density per Sample** | Total Distinct Taxa Collected | Avg Number of Taxa/Sample | Study Area Sampler Type |
|---|---|---|---|---|---|
| Dike structure | 10,726 | 536.4 | 28 | 7.3 | Individual stones by hand |
| Abandoned channel | 7,004 | 70.04 | 39 | 5.2 | Ponar grab |
| Natural bank | 1,011 | 9.4 | 26 | 1.4 | Shipek grab |
| Dike field | 1,623 | 7.4 | 32 | 0.9 | Ponar grab; Shipek grab |
| Revetted bank | 126 | 0.6 | 15 | 0.3 | Shipek grab |
| Permanent secondary channel | 3 | 0.3 | 3 | 0.3 | Shipek grab |
| Temporary secondary channel | 51 | 2.1 | 14 | 1.0 | Shipek grab |
| Main channel | 9 | 0.5 | 6 | 0.5 | Shipek grab |
| Sand bar | 12 | 1.5 | 7 | 1.0 | Shipek grab |

* After Mathis et al. (1981).
** All grab sample data are standardized to number per 0.05 $m^2$.

types of bank stabilization. On the other hand, an increased population of certain benthic macroinvertebrates could be beneficial to fish species that use them for food.

Aesthetic impacts

322. Riparian vegetation adds greatly to the aesthetic value of a stream. The uniform, artificial appearance of many forms of streambank protection tends to detract from scenic values. Clearing of floodplains for urban and agricultural uses has made riparian forests even more valuable because of their relative scarcity. Bank protection and other types of channel modification projects frequently incorporate features such as boat ramps and parking areas to facilitate recreational use by the general public. Therefore, a project may increase the usage of an aesthetic resource, even though it may degrade that resource (U. S. Army Engineer District, Sacramento 1980).

323. On the other hand, stabilization of caving and eroding banks may add to the scenic resources of a stream, particularly if natural vegetation is allowed to grow over bank protection structures. Reductions in turbidity and sediment deposition, which may be a result of bank stabilization, can also be beneficial to aesthetic values.

## Recent Developments

### Section 32 Program

324. Section 32 of Public Law 93-251, entitled "The Streambank Erosion Control Evaluation and Demonstration Act of 1974," authorized a program of demonstration projects and streambank erosion and streambank protection techniques. The Section 32 Program is therefore a major source of information on causes of streambank erosion and methods of streambank protection. The program has been organized into 10 work units:

a. Evaluation of extent of streambank erosion nationwide.

b. Literature survey and evaluation of bank protection methods of existing projects constructed under other programs.

c. Hydraulic research on effectiveness of bank protection methods.

d. Research on soil stability and identification of causes of streambank erosion.

e. Ohio River demonstration projects.

f. Missouri River demonstration projects.

g. Yazoo River Basin demonstration projects.

h. Demonstration projects on other streams nationwide.

i. Rehabilitation of demonstration projects as needed.

j. Reports to Congress and technology transfer.

The Section 32 Program does not address environmental considerations directly; however, some environmental studies have been done at Section 32 demonstration projects (U. S. Army, Office of the Chief of Engineers 1978b). This report and subsequent efforts of Project VI of the EWQOS should be considered as supplements to the Section 32 Program.

325. The first task of the Section 32 Program, a nationwide evaluation of the extent of streambank erosion, is complete. The findings were as follows: of 3.5 million stream-miles of channels in the United States, 142,000 bank-miles are undergoing serious erosion. The estimated total damages due to serious erosion are $200 million per year, while the estimated conventional protection costs for this serious erosion are $870 million per year (U. S. Army, Office of the Chief of Engineers 1978b).

Environmental work

326. Recent advances in providing environmentally compatible streambank protection include the development of new concepts regarding the use of vegetation, particularly combinations of vegetation and structural protection. Native species of wetland vegetation may be useful in erosion control. New designs for bank protection which incorporate vegetation are being demonstrated on the Sacramento and Missouri Rivers and in the Ohio and Yazoo River Basins. Environmental data are being collected at existing bank protection projects on the Missouri, Sacramento, Willamette, and Lower Mississippi Rivers.

## Vegetation

327. Allen (1978) discusses the use of wetland plants to control erosion of streambanks, reservoir shorelines, artificial islands, and other areas. Relatively little attention has been given to the use of plants to control erosion compared to the development of inanimate structures. The value of existing native plants to erosion abatement has not been fully appreciated, although native plants have been used successfully to protect streambanks in parts of Europe (Seibert 1968) and in the northeastern United States (Edminster et al. 1949).

328. Limitations. Although quite effective in some situations, wetland vegetation does have its limitations in providing riparian erosion control. Flooding often damages stands of wetland plants by covering them with debris and silt or by subjecting them to mechanical injury due to the action of floating debris. Most species of wetland plants require relatively calm water to become established, although after they are established they are effective in flowing water environments. Vegetation must be supplemented with engineering structures and materials in areas of extreme erosion and stress (Allen 1978). Vegetation is simply inadequate to stabilize banks in some situations.

329. Vegetation zones. Native vegetation may provide good streambank protection in some situations if appropriate species are selected and correctly planted. To aid in species selection, Allen (1978), Seibert (1968), and Logan et al. (1979) present a zonation of the streambank based on the duration of flooding (Figure 58). These zones may be designated as the terrace, bank, splash, and toe zones as in Figure 58, or alternately as the hardwood, softwood, reed-bank, and aquatic plant zones, respectively. Native species adapted to each zone may be identified. U. S. Army, Office of the Chief of Engineers (1980c) gives guidance on selection of flood-tolerant vegetation.

330. An example arrangement of planted vegetation for bank protection might include a stone face in the toe zone (Figure 59). Reeds and bulrushes can be used in the splash zone, while willows are suited for the bank zone. Reed canarygrass is also highly recommended by the SCS for flooded areas and on channel slopes below the mean high-water

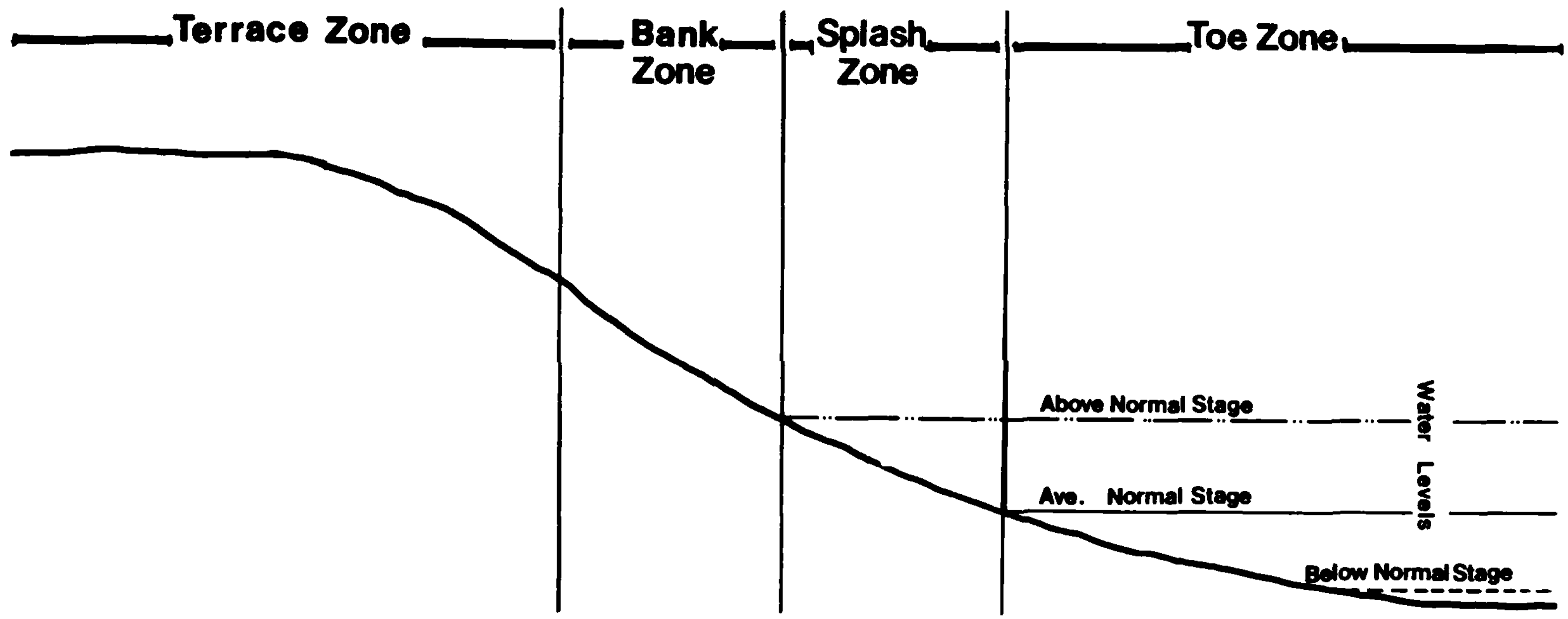



Figure 58. Streambank zonation based on duration of flooding (after Logan et al. (1979))

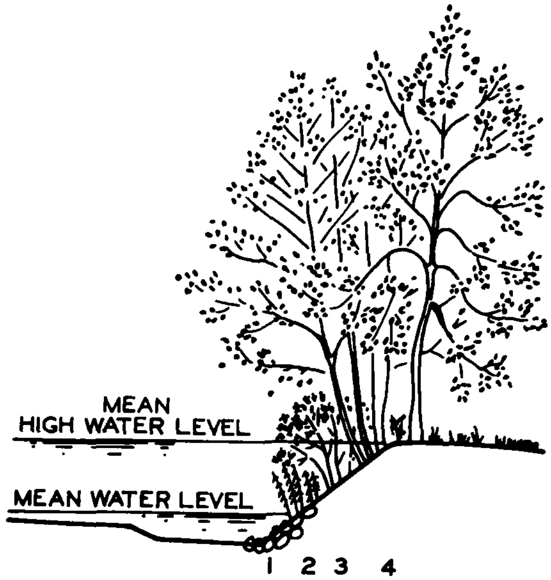



Figure 59. Streambank plantings adapted to duration of flooding (after Seibert (1968))

mark. Reed grasses give good protection through the winter. The terrace zone can support grasses, shrubs, and trees such as alders, ashes, cottonwoods, or poplars (Allen 1978, Logan et al. 1979).

331. Planting. Installation of native wetland plants on eroding streambanks requires skill and attention to the details of scheduling. Seibert (1968) and Logan et al. (1979) describe planting techniques such as seeding, sprigging, and using sod, root pads, and reed rolls. Banks may be stabilized to allow plants to root with rows of fascines, which are lengths of switches or stems of willow or other sprouting species packed together in a continuous roll 4-5 in. in diameter (Figure 60). These rolls are partially buried across the slope and are supported on the downhill side by stakes set at right angles to the slope. Logan et al. (1979) also discusses plant procurement, handling, fertilization,

Figure 60. Recently installed willow fascines (from Seibert (1968))

and mulching. Careful scheduling is necessary to minimize initial losses of plants due to delays in planting.

### Missouri River demonstratation projects

332. A number of bank protection methods that incorporate environmental considerations are being tested on the Missouri River as part of the Section 32 Program. Bank protection structures under evaluation include hard points, windrow revetment, composite revetment, reinforced revetment, and earth-core dikes. Several of these methods are used at each demonstration site (U. S. Army, Office of the Chief of Engineers 1978b).

333. Hard points. A hard point is a rock-filled projection extending perpendicular from the bank (Figure 61). The stone point extends into the river 30 to 50 ft and a substantial stone "root" is buried in the bank 30 to 50 ft to prevent flanking. The top of the hard point is covered with a thin layer of soil and gravel and seeded to reduce aesthetic and environmental impacts. Hard points are placed in series along an eroding bank. Theoretically, the bank between the hard points will scallop back to some point of equilibrium and erosion will cease until higher flow conditions are encountered. Small eddies or quiet, deep pools form downstream of each hard point, providing excellent

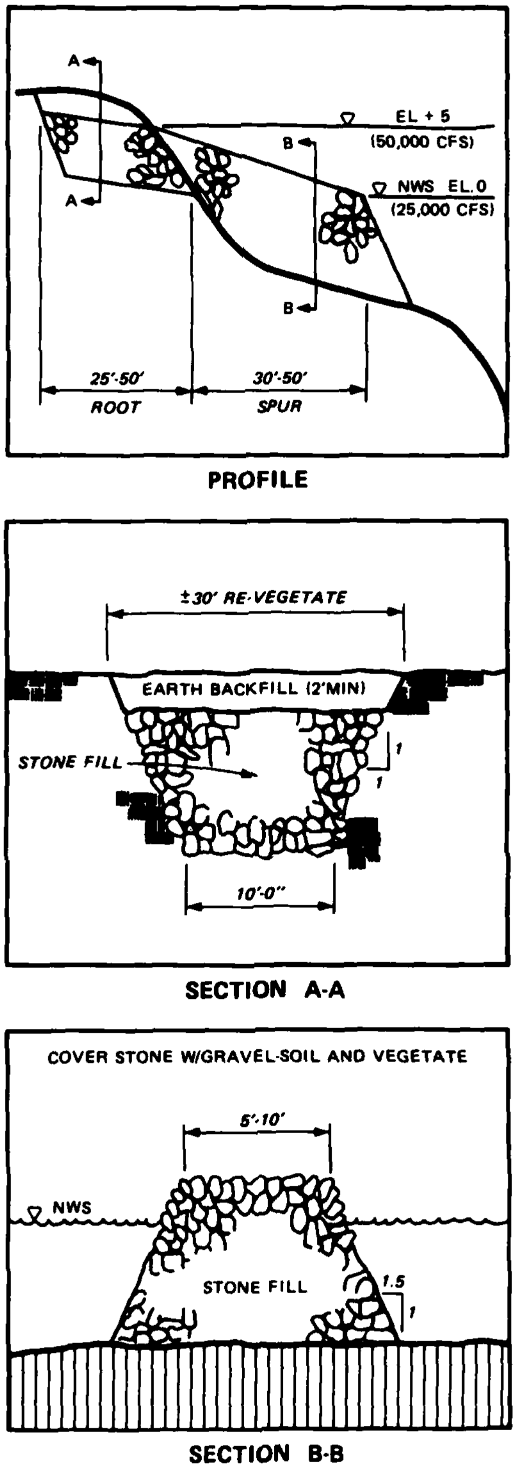



Figure 61. Hard-point profile and cross sections (from Logan et al. (1979))

aquatic habitat (Logan et al. 1979, U. S. Army, Office of the Chief of Engineers 1978b).

334. Windrow revetment. A windrow revetment is a linear mound of stone placed in a trench excavated along the top of the eroding bank (Figure 62). The trench may be backfilled over the stone or left open. As the bank erodes and undercuts the stone mound, the stone sloughs to form a blanket for the new bank at a naturally established slope. Additional stone may be added as needed or excess stone may be salvaged (U. S. Army, Office of the Chief of Engineers 1978b).

335. Composite revetment. Composite revetment is constructed with different materials at different elevations, since different zones undergo different stresses (Figure 63). The toe zone is usually inundated and not subject to freeze-thaw action. The splash zone is the zone of highest stress, and the bank zone is above normal high water. Various types of materials and vegetation are being tested for each of the zones (U. S. Army, Office of the Chief of Engineers 1978b). The composite revetment in Figure 63 shows quarry rock in the toe zone, gravel in the splash zone, and vegetation in the bank zone. Soil-cement blocks and chalk fill have also been used in the toe zone.

336. Reinforced revetment. Reinforced revetment is similar to composite revetment in the toe zone. In the splash zone and bank zone, however, the reinforced revetment substitutes intermittent structural tie-backs for the continuous bank treatments used in composite revetment (Figure 64). Each tie-back extends from the bank landward a distance of 20 ft or more. The tie-backs are spaced at various intervals and consist of excavated trenches backfilled with stone and covered with topsoil (U. S. Army, Office of the Chief of Engineers 1978b).

337. Earth-core dike. An earth-core or sandfill dike is a dike 300-1500 ft long used to stabilize a sandbar (Figure 65). The dike is built on top of the sandbar and tied back to the high bank. The upstream face and toe of the dike are protected with stone. The dike is seeded with flood-tolerant grasses (Logan et al. 1979).

338. Biological field study. A pilot field study was recently completed that investigated the environmental impact of several of the

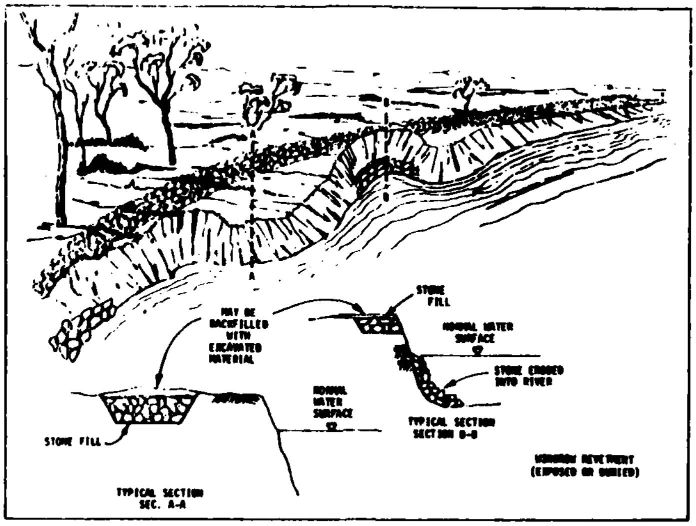



Figure 62. Windrow revetment (from U. S. Army, Office of the Chief of Engineers (1978b))

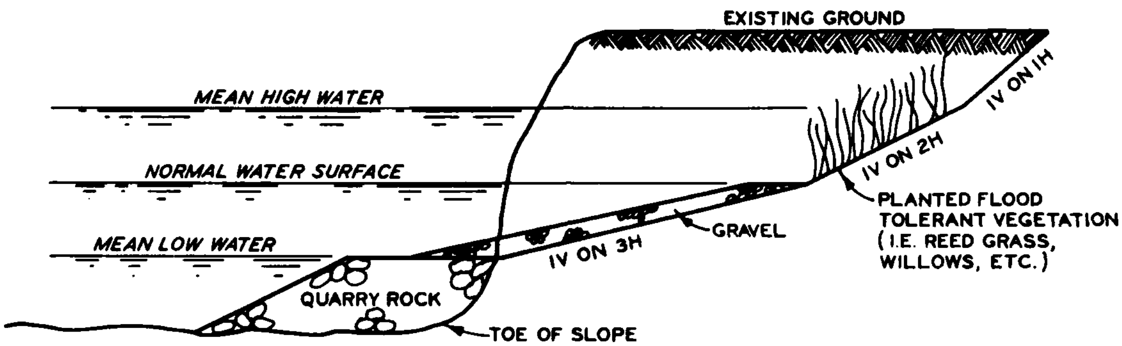



Figure 63. Composite revetment (from Allen (1978))

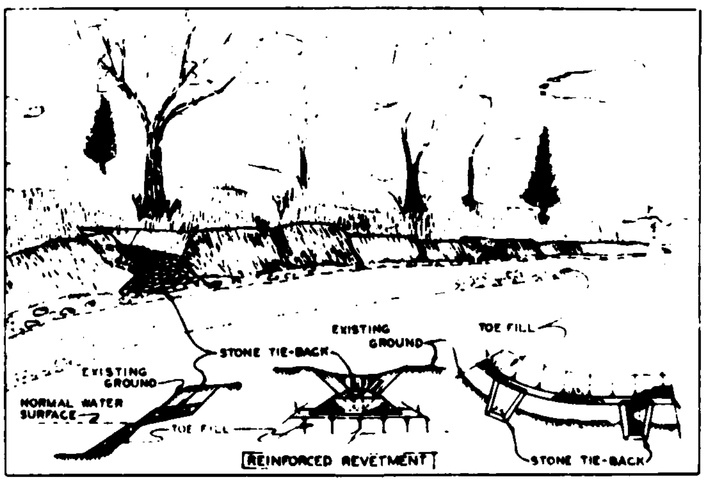
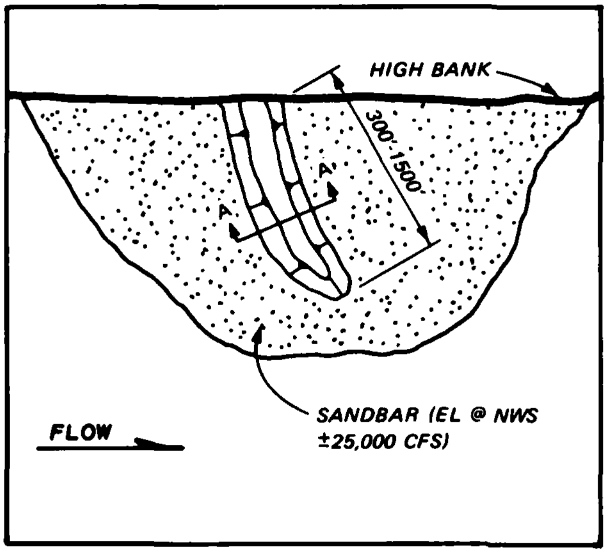
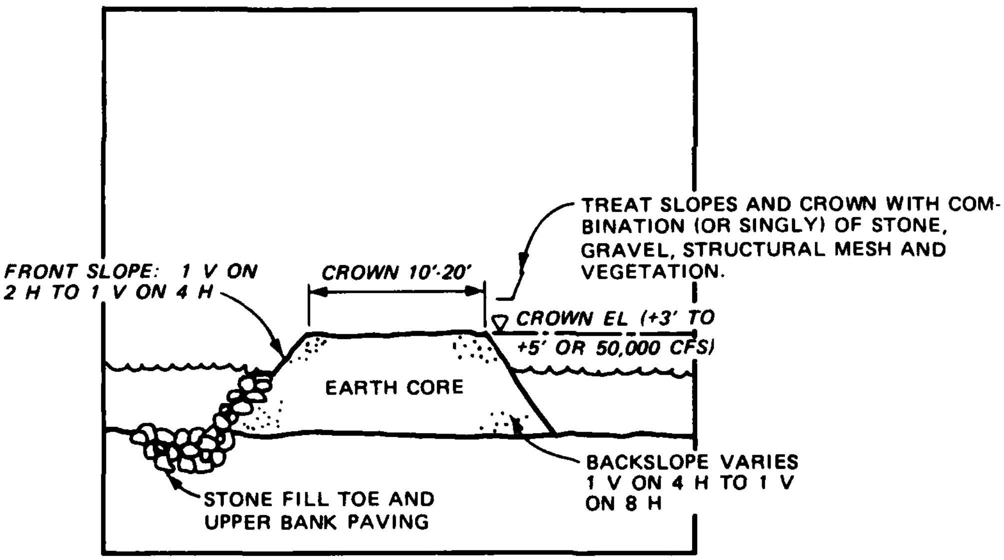



Figure 64. Reinforced revetment (from U. S. Army, Office of the Chief of Engineers (1978b))




**PLAN**




**SECTION A-A**

NOTE: CROWN ELEVATION GENERALLY LEVEL FOR ANY GIVEN STRUCTURES.

Figure 65. Earth-core dike plan and cross section (from Logan et al. (1979))

Missouri River Section 32 demonstration projects in the vicinity of Washburn, N. Dak. (river mile 1351-1365). The study was a cooperative effort by Project V of the EWQOS, the U. S. Army Engineer District, Omaha, and the U. S. Fish and Wildlife Service. Sampled sites included unprotected banks, stone-faced earth-core dikes, L-head dikes, wing dikes, hard points, and riprap revetments. Measurements were made of water quality parameters, sediment grain size, and current velocity. Fish and benthic invertebrates were sampled. A report on the study is in preparation.

Streambank protection
on the Sacramento River

339. Increased public interest in preserving the environmental resources of the Sacramento River Basin has led to the identification of some alternatives to conventional streambank protection with rock revetment (Mifkovic and Petersen 1975). Streambank protection is necessary along much of the Sacramento River to protect the integrity of levees and to prevent losses of structures or land. A typical Sacramento River levee cross section showing bank protection is shown in Figures 66a, b, and c. Alternative designs have focused on preserving and restoring riparian vegetation on the berm between the levee and the channel.

340. Some alternative design and construction practices that have been considered include:

- a. Selective clearing and retention of vegetation and replacement of unavoidably lost vegetation at construction sites.
- b. Restoration of berm areas (Figure 66c).
- c. Preservation of part of the existing berm areas by steepening the protected slope. A steeper slope requires less area.
- d. The requirement that construction be done from the waterside using floating equipment.
- e. The reduction of the elevation of the top of rock revetment to a sustained high flow level (Figure 67a, b).
- f. Preservation of habitat on protected berms by environmental easements.
- g. Inclusion of recreation facilities at some bank protection sites (Mifkovic and Petersen 1975).

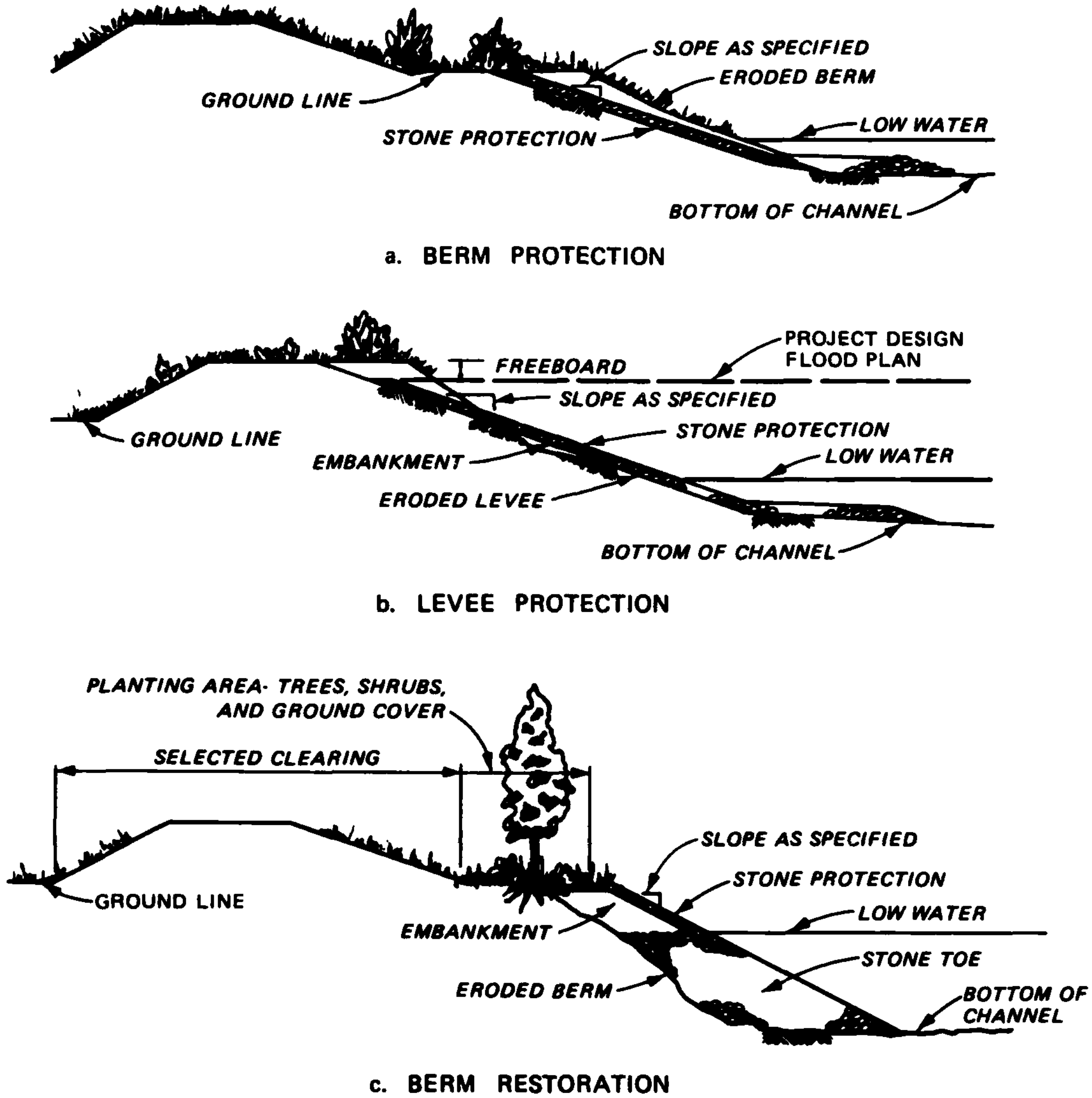
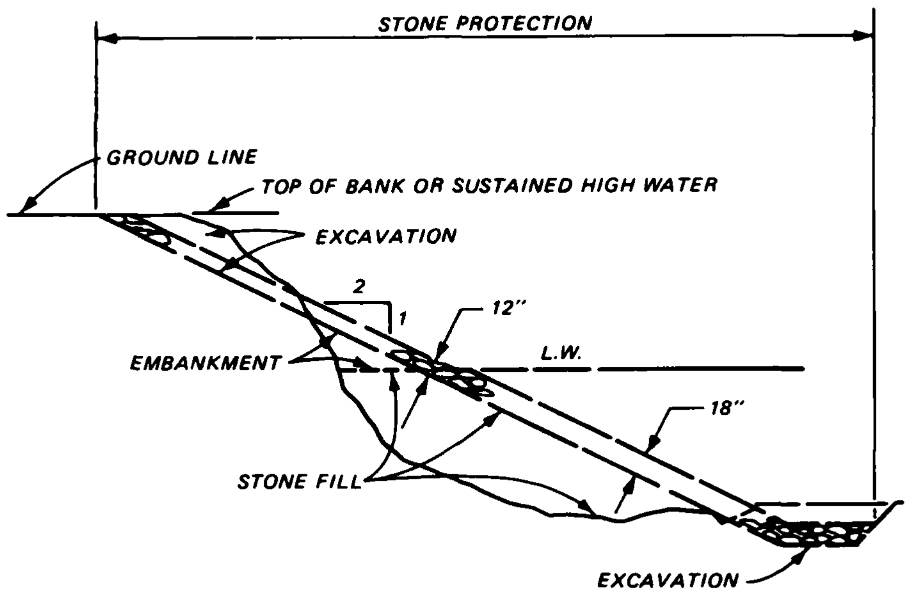
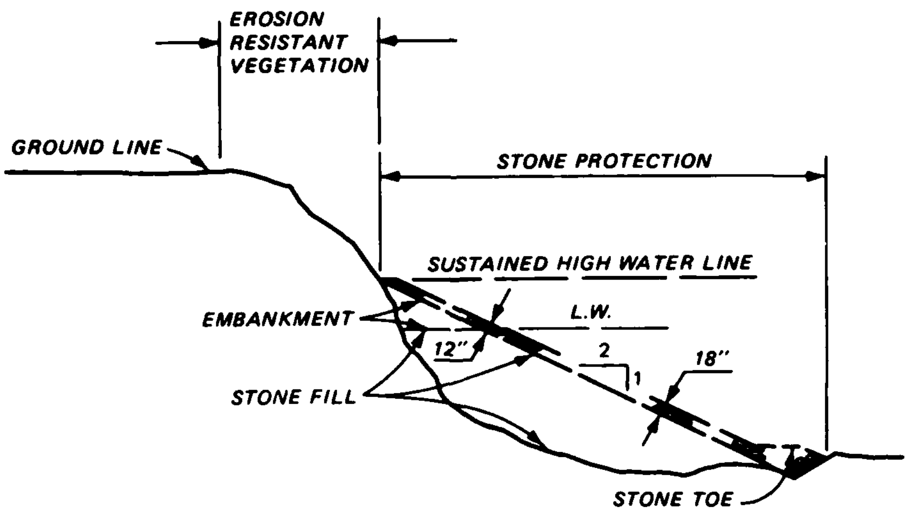



Figure 66. Streambank protection designs, Sacramento River (after Mifkovic and Petersen (1975))

341. Several other alternatives have been considered by the Sacramento District, CE, to reduce the impacts of bank protection projects. Alternatives that do not appear to be feasible include modified operation of upstream flood control projects, the use of bank protection materials other than rock revetment such as sheet piling or concrete blocks with voids to permit vegetative growth, construction of new berms with dredged material, and the use of flatter bank slopes and vegetative




a. Standard rock revetment




b. Modified design--top of revetment lowered to sustained high water elevation

Figure 67. Rock revetment designs, Sacramento River (after U. S. Army Engineer District, Sacramento (1980))

protection instead of rock revetment. These alternatives have been found to be either ineffective in controlling bank erosion or uneconomical (U. S. Army Engineer District, Sacramento 1972 and 1975).

342. An ongoing effort of cooperative research the State of California, the U. S. Fish and Wildlife Service, and the Sacramento District, CE, seeks to quantify the biological effects of streambank protection along the Sacramento River. Data are being collected on terrestrial vegetation, birds, fish, and benthic macroinvertebrates at a number of representative sites (Finn and Villa 1979).

Ohio River Basin
demonstration projects

343. As part of the Section 32 Program, several streambank protection methods that feature potentially low-cost materials and techniques are being tested on the Ohio River and its tributaries (U. S. Army, Office of the Chief of Engineers 1978b). Several of these methods have potential for reducing adverse environmental impacts.

344. Vegetation is being widely used at the Ohio River demonstration sites. Both grasses and native flood-tolerant plants are being used on a wide range of bank slopes and with several types of structural toe protection. Additional detail is found in U. S. Army, Office of the Chief of Engineers (1978b). Although plant growth is being monitored at these sites, no additional ecological data are being collected.

Yazoo River Basin
demonstration projects

345. Section 32 demonstration projects on small streams in the northern part of the Yazoo River Basin include the use of willow sprigging on upper banks. Willows are used in conjunction with certain types of structures such as rubber tire revetments. The willow shoots are planted in the revetment. Additional information may be obtained from U. S. Army, Office of the Chief of Engineers (1978b).

346. Another technique used in some Yazoo Basin streambank protection projects is the placement of riprap on the toe of eroding banks without disturbing upper bank vegetation (Figure 68). This

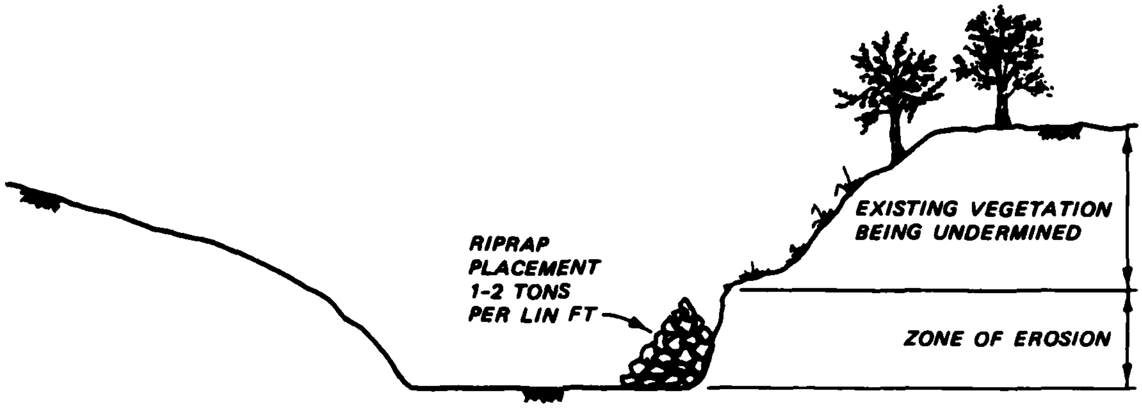



Figure 68. Streambank protection technique used to preserve riparian vegetation (Riprap is placed from streambed or opposite bank without disturbing vegetation on protected bank; after personal communication, Charles Elliot.)

technique is applied only where there is a good stand of vegetation on the upper bank. Project specifications direct that existing vegetation not be disturbed, thus requiring riprap placement from the opposite bank or streambed in many cases. The riprap is placed at a specified weight per linear foot of streambank. The riprap is shaped in a ridge high enough to protect the actively eroding zone.*

347. Some Yazoo Basin demonstration projects feature the use of grade-control structures to stabilize streams with eroding banks and beds. These structures may alleviate the need for extensive direct streambank protection, and thus reduce adverse environmental impacts. However, grade-control structures may have adverse environmental impacts of their own. Winger et al. (1976) found that properly designed sheet-pile stabilizers installed as part of a channel modification project were effective in providing vertical relief (a pool-riffle sequence) and good fish habitat. However, structures installed at too high an elevation or too close together ponded water over potential riffle areas and thus had a negative influence on fish habitat. Grade-control structures can also block fish migratory routes. Additional discussion of

* Personal communication, Charles Elliot, River Stabilization Branch, U. S. Army Engineer District, Vicksburg, Vicksburg, Miss.

the environmental impact of grade-control structures is found in Part III of this report.

Willamette River
demonstration project

348. Extensive bank protection works have been constructed along the Willamette River and its tributaries over several decades. Typical bank protection works are stone riprap revetment placed at a 1V on 2H slope using traditional land-based construction methods. Most bank protection works in the Willamette Basin are constructed to protect agricultural lands, although some do protect structures (Bierly and Associates 1980).

349. Once the revetments are constructed, receding floodwaters deposit sediment in interstitial areas and provide sites for colonization by plants. Vines and adventitious rooting plants often encroach upon the revetment from uncleared areas. In the past, routine revetment maintenance included removal of all vegetation down to the sod layer to facilitate inspection. Clearing was also performed to prevent damage to the revetment by trees uprooting during storm events and dislocating riprap from the face of the revetment. Documentation of damage to revetments attributable to vegetation is not available. More recently, the maintenance policy for revetments was modified as a result of recommendations by an interagency committee to restrict clearing to material greater than 6 ft in height or 2 in. in diameter (Bierly and Associates 1980).*

350. An ongoing demonstration project sponsored by the U. S. Army Engineer District, Portland seeks to determine the extent of revetment damages caused by vegetation. Further study will weigh the cost of these damages against possible fish and wildlife benefits gained. The first phase of the demonstration project was to document the existing vegetational cover at three revetment locations. The vegetation present at the three sites displayed a distribution of species from the top of the bank to the low-water level similar to that proposed by Seibert

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* Supplemented with personal communication, U. S. Army Engineer District, Portland.

(1968) and Logan et al. (1979) for planting vegetational streambank protection.

351. In an earlier study sponsored by the Portland District, CE, Klingeman and Bradley (1976) examined the feasibility of stabilizing Willamette River Basin streambanks by "natural" means. Natural means were defined as methods that could be used by an individual landowner such as physical sloping of the bank, vegetative management, and land management adjacent to the streambank. These methods were not found to be adequate to protect critical areas such as the concave banks of sharp bends, but were found to be useful for eroding banks along straight reaches, convex banks, and flat curves. A combination of structural protection at the toe of the bank and natural methods of protection higher on the bank was suggested. The study did not compare the environmental impacts of the various methods of bank protection (Klingeman and Bradley 1976).

### Lower Mississippi River field studies

352. Extensive environmental data on the environmental effects of existing river-training structures on the Lower Mississippi River have been collected as part of the EWQOS waterways field studies. Water quality, sediments, fish, and benthic macroinvertebrates have been sampled at selected sites that are representative of the various types of aquatic habitats present along the river at various flow conditions. Dike structures and revetted banks are two of the habitat types sampled.

## Summary

353. Streambank protection is used to counter the process of streambank erosion, which is a natural geomorphic process. Streambank erosion rates are governed by a host of variables including discharge, sediment load, grain size, bed slope, valley slope, and sinuosity. Natural or man-induced changes in the channel or basin of a stream may accelerate or decelerate streambank erosion.

354. Streambank protection may be used to control local

erosion/deposition problems, or to control the natural migration of a stream channel to produce a more favorable channel configuration for flood control and navigation.

355. Streambank protection methods may be loosely categorized as direct or indirect, permeable or impermeable, and structural or nonstructural. Vegetation is a nonstructural method of bank protection. Keown et al. (1977) present an excellent review of bank protection methods.

356. The design of streambank protection at present is a nonstandard procedure usually based on experience and subjective judgment. Some analytical tools are available for limited use. Of the widely used methods of bank protection, more design information is available on stone riprap. However, existing guidance for riprap design is somewhat fragmented and is devoid of environmental considerations. Limited information is available on selection and planting of vegetative cover for bank protection.

357. Environmental data from streambank protection projects must always be evaluated in light of site-specific factors, such as the presence of other types of channel modifications. Streambank protection has been observed to affect the morphology and water quality of some streams. Reductions in stream lengths, riparian habitat, and/or the rate of channel migration--all of which sometimes accompany large-scale channel stabilization--may be the most serious long-term environmental effect of streambank protection. Stern and Stern (1980a and 1980b) present a literature review of the physical and chemical effects of bank stabilization on small streams.

358. Biological effects of streambank protection may be classified as terrestrial or aquatic. The removal of riparian vegetation may have both terrestrial and aquatic effects. Populations of some species of birds are influenced by the presence of riparian vegetation. Bank stabilization may improve aquatic habitat by reducing sediment loads and providing stable substrate for macroinvertebrates and cover for fish. Stone seems to provide better substrate than steel.

359. Bank protection projects may degrade or improve the scenic

resources of a stream. Bank protection projects sometimes result in improved public access to the stream.

360. The Section 32 Program is a program of demonstration projects and research on the problem of bank erosion and on bank protection techniques. The Section 32 Program does not deal directly with environmental considerations.

361. Recent developments in streambank protection include new ideas regarding the use of native species of flood-tolerant plants, particularly in combination with some form of structure. Ongoing field studies on the Missouri, Sacramento, Willamette, and Lower Mississippi Rivers should provide additional information about the environmental effects of bank protection projects and possible methods to reduce adverse environmental impacts. Ongoing demonstration projects in the Ohio and Yazoo River Basins are testing various combinations of vegetation and structure.

362. Additional research is needed to incorporate environmental considerations into the design of streambank protection projects. The types of materials, vegetation, and structures most beneficial to riparian communities need to be identified and documented.

363. Greater attention should be given to the use of native flood-tolerant plant species. Existing information allows the flood-tolerance of plants to be rated; additional study is needed regarding the performance of various species under a variety of conditions (Whitlow and Harris 1979). Criteria for plant species selection should include the habitat value of the plant species as well as flood tolerance. More information is needed on effective and economical planting techniques and on combinations of structures and vegetation.

364. Design of bank protection projects should include consideration of both local and basin-wide effects on riparian vegetation and stream morphology. The long-term consequences of channel stabilization on riverine ecosystems are presently unknown.

## PART VI: LEVEES

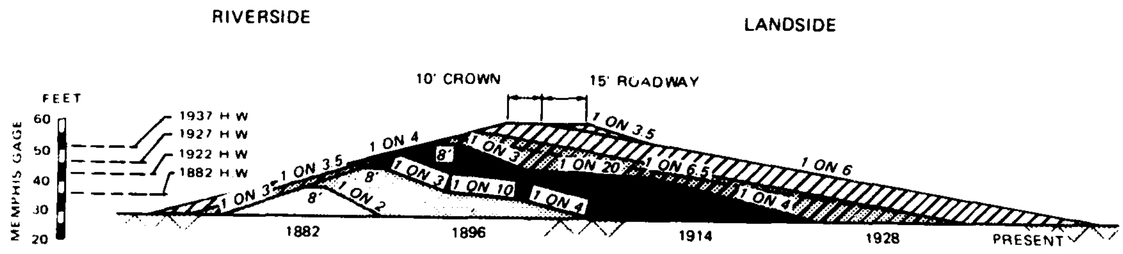
365. Levees are earthen embankments that furnish flood protection from seasonal high water. Normally, levees are subject to water loading for only a few days or weeks a year. Levees are used to protect both urban and agricultural areas. They may lie parallel to and on either side of a channel, or they may partially or completely encircle the protected area.

366. This part consists of six major sections. The first section describes levee projects in general terms. Existing levee design, construction, and maintenance practices are presented next. The third section is a review of the known environmental impacts of levee projects. Recent developments in levee design, construction, and maintenance that hold promise for minimizing adverse environmental impacts are discussed in the fourth section. The last two sections are the summary and conclusions.

### Purposes and Descriptions of Levee Projects

367. Levees prevent rising floodwaters from inundating a portion of floodplain by confining the flood flows to a narrower, deeper floodway. Individual landowners sometimes construct levees along short reaches, but most levees are public works projects that are a part of an overall basin-wide flood control plan. Levees are used in conjunction with reservoirs, floodways, control structures, and various types of channel modifications to reduce and control the extent and duration of flooding.

368. Levee enlargement projects are common, particularly just after levees are threatened or fail during catastrophic floods with resulting public interest in increased flood protection. Higher flood stages due to changes in channel capacity also encourage levee enlargement. Figure 69 depicts the evolution of the standard cross section used for levees on the Lower Mississippi River between 1882 and 1937.




SCALE

20 0 20 40 60 80 FT

DIMENSIONS OF CROSS SECTIONS

| YEAR | HEIGHT FEET | BASE WIDTH FEET | AREA SQ FEET |
|---|---|---|---|
| 1882 | 9.0 | 53.0 | 274 |
| 1896 | 15.5 | 120.5 | 951 |
| 1914 | 24.0 | 200.0 | 2455 |
| 1928 | 27.0 | 260.0 | 3645 |
| PRESENT | 30.5 | 315.0 | 4956 |

Figure 69. Evolution of standard levee section, Lower Mississippi River, 1882 to 1972 (from Moore (1972))

General description

369. A levee site consists of protected and unprotected floodplains separated by the levee embankment (Figure 70). The levee embankment is usually a trapezoid with an access road along the crown. A long, low berm may be built on the landside of the levee to control underseepage. Material for levee construction is normally obtained from nearby borrow pits on the riverside. Riverside land enclosed by levees is referred to as batture. The land between the levee and the water's edge is called the foreshore, or sometimes is called a berm. Appurtenant structures such as cutoff trenches, relief wells, collector ditches, pumping stations, and control structures are used to handle underseepage and interior drainage.

370. Floodwalls. In urban areas where land costs are high, levees or levee enlargements may be replaced by concrete floodwalls. Floodwalls are more expensive to construct than levees, but require much less area. Floodwalls may be I-shaped if less than 7 ft high, or shaped like an inverted T if greater than 7 ft high. The horizontal members of the inverted T are embedded in the foundation and act as wide cantilever beams in resisting hydrostatic pressures acting against the wall (U. S. Army, Office of the Chief of Engineers 1978a).

Figure 70. Mississippi River main-line levee (Note borrow pit lake in foreground; photo courtesy of U. S. Army Engineer District, Vicksburg.)

371. Borrow areas. Fill for levees is usually obtained from shallow pits or channels adjacent to the riverside of the levee embankment. Although this material is often far from ideal, economic necessity dictates its use. Shortcomings of fill material are sometimes compensated for by the use of larger levee sections. Embankments subject to water loading for prolonged periods require more stringent selection of fill (U. S. Army, Office of the Chief of Engineers 1978a).

372. Typical layout for a levee borrow scheme is a series of long, shallow pits parallel to the riverside of the levee. The pits are separated at regular intervals by short, unexcavated zones known as traverses. The traverses provide roadways across the borrow area and prevent excessive velocities through the borrow area during high water. When sufficient borrow is unavailable adjacent to the levee, fill may be obtained from channel enlargement or from large, centralized borrow areas (U. S. Army, Office of the Chief of Engineers 1978a).

373. Although locating borrow areas on the riverside of levees

sometimes requires more clearing than for landside areas, there are several advantages to the riverside location. Borrow pits normally fill with water after construction, and riverside pits can exchange water and organisms with the river. Fewer seepage problems are associated with riverside borrow pits, and riverside pits are normally less subject to pollution from agricultural runoff than landside pits. Riverside pits are gradually filled with sediment by falling floodwaters, thus obliterating some of the man-made changes in the landscape (U. S. Army, Office of the Chief of Engineers 1978a).

374. Borrow pits are normally constructed with slopes gentle enough to ensure stability and to prevent erosion when overtopped by high flows. Borrow pits in agricultural areas may be finished with slopes that facilitate drainage and the use of farm equipment (U. S. Army, Office of the Chief of Engineers 1978a).

Seepage

375. Underseepage is a term used to describe the migration of water through and under a levee from the riverside to the landside during high water. This seepage can carry soil and sand particles and create "sand boils" on the landside of the levee. These boils can rapidly become "pipes" and lead to the subsidence and total failure of the levee (U. S. Army, Office of the Chief of Engineers 1978a).

376. Various features are incorporated into levee projects to handle seepage. Seepage under the levee foundation may be combatted by an impervious wall or cutoff beneath the levee, blankets of impervious soils on the riverside, or long berms or pressure-relief wells on the landside. Seepage through the levee embankment itself may be controlled by the use of layers or zones of pervious materials within the embankment. These materials convey the seepage with little or no internal erosion (U. S. Army, Office of the Chief of Engineers 1978a).

Access roads

377. An all-weather access road is normally built on the levee crown. Occasionally public roads or highways are built on levee crowns. Levee access roads are essential for levee maintenance, inspection, and flood-fighting. Sometimes levee roadways include wider areas, or

"turnarounds," to allow two vehicles to pass and ramps to allow vehicles to descend to the base of the slope (U. S. Army, Office of the Chief of Engineers 1978a). Use of levee roads, embankments, and borrow pits by the general public for recreational activities varies from project to project. Such activities are generally governed by local sponsors and landowners.

378. Levees must be protected from the erosive forces of river currents, wave wash, and rainfall (Moore 1972). A heavy growth of sod is usually sufficient to prevent rain-caused erosion. Levees sited well back from the river channel and protected by a screen of large vegetation on the foreshore will normally need little protection from waves or currents. However, levees built close to river channels with little or no foreshore require some type of structural bank protection. Levees constructed of highly erodible soils or exposed to local turbulence and scour also require bank protection (U. S. Army, Office of the Chief of Engineers 1978a). Bank protection methods in common use for levee systems include riprap revetment (Mifkovic and Petersen 1975) and low lateral dikes built parallel to the levee (Moore 1972). Dikes may be built of riprap or broken concrete. Several types of slope protection have been used for levee slopes at some time, including concrete paving and ACM (U. S. Army, Office of the Chief of Engineers 1978a).

## Existing Levee Design, Construction, and Maintenance Practices

### Design

379. Existing CE levee design and construction practices are described in EM 1110-2-1913, Design and Construction of Levees (U. S. Army, Office of the Chief of Engineers 1978a). Levee systems are usually planned and sited as part of a larger basin-wide planning process. Input to the levee design process includes desired levee locations and design flood elevations and durations. Levee crest elevations are determined by the design flood elevation plus an allowance for settlement and freeboard. The freeboard is to allow for wave action and uncertainties in design.

380. Engineer Manual 1110-2-1913 gives a general levee design procedure organized into ten main steps. As currently practiced, levee design involves thorough study of the foundation conditions and available borrow material. Levee cross sections are sized based on the method of construction to be used (compacted, semicompacted, or uncompacted) and land values. In many cases a standard levee section will be developed for a particular river or basin. Ease of construction and maintenance affect slope selection. After trial levee dimensions are computed for each reach, the trial cross sections are analyzed for seepage, stability, and settlement (U. S. Army, Office of the Chief of Engineers 1978a).

381. Environmental considerations are not a major element in current design procedures for levee projects. Some recent levee projects have incorporated environmental considerations in three general areas: (a) design and final treatment of borrow pits, (b) selection of vegetation for levee slopes, and (c) control of construction activities to minimize adverse impacts. Borrow pits that are carefully located and constructed with appropriate side slopes and depths can become shallow lakes that offer habitat for fish and wildlife and recreational opportunities after project construction. Borrow pit side slopes are constrained by stability considerations, and borrow pit depths may be limited by underseepage considerations. Levee slopes can be planted with grasses or herbaceous plants that offer food and cover for birds and small mammals. Construction techniques to minimize erosion and sediment inputs to streams and waterways and to minimize disturbance of wildlife habitats are coming into widespread use. Additional discussion of environmental considerations is found below.

382. Landscape planting can be used to reduce the aesthetic impacts of levees, floodwalls, and pumping stations. Guidance for landscape planting at levee projects is found in EM 1110-2-301 (U. S. Army, Office of the Chief of Engineers 1972). Corps policy dictates that appropriate landscape plantings of trees, shrubs, vines, and grasses be incorporated into the design of levees when the safety of the structure is not compromised and the maintenance of the facility is not seriously

affected. Landscape planting is particularly recommended for urban levees and for levees at pumping installations and public road crossings. Plantings can be facilitated by overfilling the landside of the levee embankment and planting selected species on the overbuilt area in such a way as to maintain a 3-ft minimum root-free zone between the deepest expected penetration of plant roots and the face of the basic project structure (Figure 71).

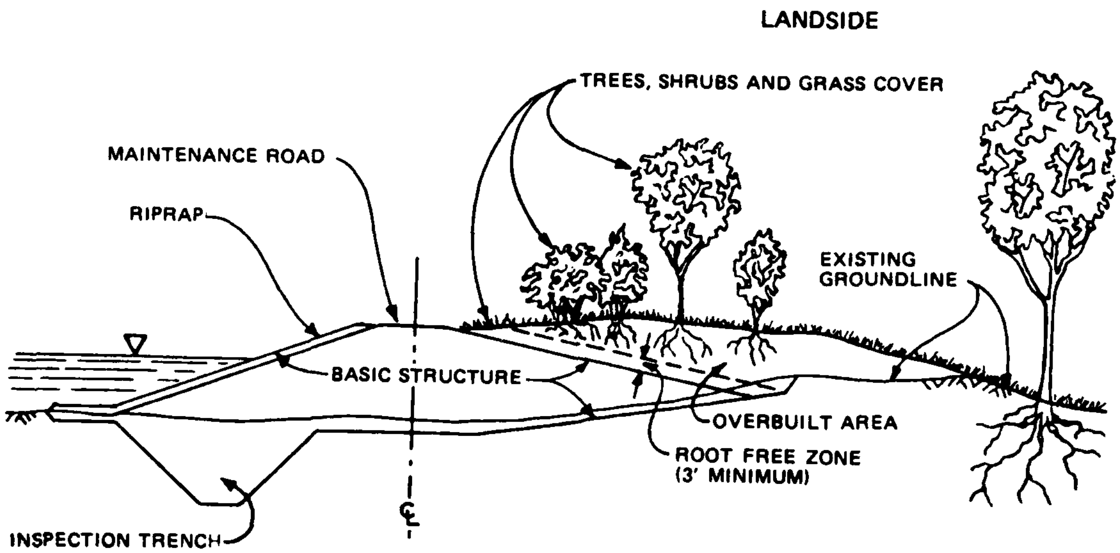



Figure 71. Corps policy for planting levee embankments (after U. S. Army, Office of the Chief of Engineers (1972))

## Construction

383. The earliest levees were built using human and animal labor. Special machines were designed and employed in levee construction in the 1920's and 1930's. Current practice generally employs typical heavy earthmoving equipment. Levees may be classified according to construction methods as compacted, semicompacted, or uncompacted. Compacted levees may be built higher and steeper. Compacted and semicompacted levees are generally built or enlarged using heavy equipment such as bulldozers, scrapers, and draglines. Compaction may be accomplished using hauling and spreading equipment or with sheepsfoot or rubber-tired rollers. Uncompacted levees may be built using hydraulically placed fill or cast in place with a clam shell (U. S. Army, Office of the Chief of Engineers 1978a).

384. Minimum foundation preparation for levees consists of clearing and grubbing. Some sites also require stripping and/or inspection trenches. Clearing consists of the removal of all trees, brush, loose stone, abandoned structures, etc. above the ground surface. Borrow areas must also be cleared. Grubbing consists of the removal of buried objects such as stumps within the levee foundation area. Stripping is the removal of all low-growing vegetation and organic top soil, usually to a depth of 2-12 in. Debris from clearing and grubbing is either burned or buried, and stripped top soil is usually stockpiled for later use on levee slopes and berms. Inspection trenches are sometimes dug prior to levee construction to expose or intercept any undesirable subsurface features (U. S. Army, Office of the Chief of Engineers 1978a).

385. After construction is complete, levee slopes are seeded or turfed to prevent erosion. Borrow pits are shaped and smoothed to final grade and vegetation may be planted around or within the borrow area. Ditches and culverts are sometimes installed to allow borrow pits to drain as river stage falls (U. S. Army, Office of the Chief of Engineers 1978a).

386. If existing levee heights are judged to be insufficient, levees may be enlarged. Levee enlargements are accomplished by adding more earth to the embankment or by building a floodwall on the crown of the existing levee. Earthen enlargements are classified as landside, riverside, or straddle enlargements, depending on the placement of the additional fill. Riverside enlargements are usually most economical due to the proximity of riverside borrow and the fact that additional right-of-way is cheaper on the riverside (U. S. Army, Office of the Chief of Engineers 1978a).

Maintenance and emergency operations

387. Local sponsors of levee projects are responsible by law for maintaining the levees in accordance with Federal regulations (Section 208.10, Title 33, Code of Federal Regulations; U. S. Army, Office of the Chief of Engineers 1967b and 1968a). The basic requirement of the regulations is that no condition be allowed that impairs levee inspection, maintenance, floodfighting capabilities, or restricts the passage of

flood flows. The regulations require that measures be taken to maintain and promote a good growth of sod and exterminate burrowing animals. Regular mowing of grass and weeds is required, although burning is also allowed for some projects in the western United States. Herbicides and livestock grazing are also used to control levee vegetation. Generally grass is maintained between 2 and 12 in. high. Regular removal of wild growth, debris, and drift and repair of erosion damage is also required. Levee maintenance must be documented by semiannual reports to the District Engineer.

388. Large vegetation, such as shrubs and trees, is not normally allowed on levees. During flood flows large trees can cause eddy currents and deflect flows which erode the levee. Wind and wave action can uproot large trees, creating a large hole and increasing the danger of levee failure. Tree roots can provide avenues that allow water to seep into and through levees. Dense vegetation can make detection of eroding zones and boils during floodfighting operations more difficult.

389. Trees and shrubs planted on levees specifically for aesthetic or recreational purposes may be allowed to remain (U. S. Army, Office of the Chief of Engineers 1968a). Special plantings on levees also must be maintained by the local agency responsible for maintenance (U. S. Army, Office of the Chief of Engineers 1972).

390. Emergency operation of levee projects, or floodfighting, is also the responsibility of the local sponsor, although CE offices may render assistance in emergencies. Federal regulations require that levees be patrolled continuously during periods of high water and inspected for seepage, saturated areas, or sand boils. Active sand boils are ringed with sand bags. Signs of impending slides, sloughs, erosion damage, and overtopping are also monitored. Immediate action is taken to control any condition that endangers the levee (Section 208.10, Title 33, Code of Federal Regulations). When levees are in danger of overtopping, material is sometimes scraped from the landside of the embankment up to the crown to temporarily raise the levee (U. S. Army, Office of the Chief of Engineers 1978a).

## Environmental Impacts of Levees

### Short-term impacts

391. The short-term environmental impacts of levee construction are similar to the impacts of any large construction project. Temporary increases in sediment concentration and turbidity in nearby streams and generation of dust, smoke, and noise are characteristic of levee construction. Problems of erosion, sedimentation, and increased turbidity can be addressed by careful construction and typical pollution abatement techniques for construction projects such as sediment ponds, seeding and mulching, and drainage control.

### Long-term impacts

392. The long-term adverse environmental impacts of levees are related to the alteration of the hydrologic regimes on both the landside and riverside of the levee and the loss of riparian habitat due to the area requirements of the levee structure. The most significant environmental impacts of levees are directly related to the basic purpose of the levee system, the prevention of inundation of the protected floodplain.

### River hydraulics

393. Levees alter river hydraulics by confining overbank flows through the leveed reach to a narrower cross section. Confining the river between the levees has two main effects on river hydraulics: (a) stages are increased for overbank flows over stages for similar discharges under unleveed conditions and (b) peak discharges are increased. Levees also prevent the deposition of sediments in the protected floodplain. In most situations this effect will be insignificant because deposition in the protected floodplain occurs at an extremely slow rate.

394. Levees tend to increase stages of overbank flows because the flow is confined to a narrower cross section. The effect of levees on stage may be obscured by changes in Manning's coefficient and by the presence of other types of channel modifications such as dikes. The study of the effects of levees on the stage-discharge relationship is further complicated by gaps and errors in historic stage and discharge data.

395. Stevens, Simons, and Schumm (1975) estimated that levees and dikes on the Middle Mississippi River had increased the stage for a discharge of 800,000-900,000 cfs by about 10 ft at St. Louis. The relative amount of this increase attributable to dikes as opposed to levees and the reliability of the historical hydrology data were subjects of lively discussion (Dyhouse 1978, Stevens 1976, Strauser and Long 1976, Westphal and Munger 1976, and Stevens, Simons, and Schumm 1976). Dyhouse (1978) argued that the channel roughness had actually decreased slightly and the slope increased slightly since the installation of dikes. Therefore, flow capacity for flows less than or equal to bankfull was not significantly affected by river stabilization, and the aforementioned 10-ft increase in flood stage was due to levee confinement, flow measurement errors, and other factors.

396. Overbank flows in an unleveed stream spread out over the floodplain. The floodplain acts as a reservoir, storing part of the floodwaters until the river stage falls. By reducing the floodplain storage, levees increase peak discharges of overbank flows (Stevens, Simons, and Schumm 1975). The influence of other types of channel modifications, such as flood-control reservoirs, floodways, and cutoffs, makes it difficult to measure or estimate the effect of levees on peak discharges. Streamflow records are sometimes too brief or of insufficient quality to compare pre- and postleveed conditions. An idea of the importance of levees on flood peak attenuation may be obtained by computing the ratio of the floodplain storage volume to the volume of water discharged during the flood event (Simons et al. 1975). Simons et al. (1975) concluded that levees along the Middle Mississippi River had no appreciable influence on flood peaks.

<u>Changes in hydrologic regimes</u>

397. An unaltered stream will periodically overflow its banks and inundate a large portion of its floodplain. The flooded areas provide important habitat for aquatic organisms and waterfowl. The seasonal flooding also creates conditions favorable for the growth of a diverse plant community adapted to floodplain conditions. Although floods can have a destructive effect on floodplain flora and fauna, these

communities are adapted to periodic flooding and recover quickly from its effects.

398. Forested wetlands and bottomland hardwood forests have multiple values (Wharton 1970). Timber production is perhaps the most obvious. These areas are usually highly productive biologically and provide scarce habitat to a diverse wildlife community. The arrangement of bottomland habitat in a corridor makes it more valuable to many species than an equal acreage in a single block. When flooded, the forested wetland provides spawning and nursery areas for some species of fish (Hall 1974, Breder and Rosen 1966, Hess and Winger 1976) and habitat for waterfowl. Forested wetlands also have aesthetic, recreational, and educational values. The increasing relative scarcity of forested wetlands makes remaining tracts more valuable for these uses (Wharton 1970).

399. Bottomlands also influence the quantity and quality of water in a riverine system. The floodplain acts as a storage reservoir for overbank floods. In some systems, overbank flooding allows sediment to be deposited on the floodplain and organic wastes to be degraded (Wharton 1970).

400. The installation of an extensive levee system has a dramatic effect on floodplain hydrologic regimes. Areas on the landside of the levees no longer experience seasonal flooding from the leveed stream. Flooding on the landside of levee systems is limited to situations when pumping stations and control structures are unable to provide adequate interior drainage, or when unleveed tributary streams flood.

401. The drier conditions on the landside of levees change the process of natural succession. Klein, Daley, and Wedum (1975) found that levees along the Upper Mississippi and Lower Illinois Rivers tended to promote the pin oak community over the silver maple-cottonwood community by creating drier conditions. Terpening et al. (1974) observed similar changes along the Middle Mississippi River. The response of woody riparian and wetland communities to water-level changes has been documented for various regions of the United States by Teskey and Hinckley (1977a, 1977b, 1977c, 1978a, 1978b, and 1978c).

402. While the levee creates drier conditions on the landside, in

most cases the battured lands (defined as lands between the levee and the streambank) will experience deeper and more prolonged flooding. Fluctuations tend to be more extreme, with extreme conditions more common and intermediate conditions less common. The wetter hydrologic regime favors some species of plants and animals and hinders others. In general, the flooding on the riverside of levees restricts the development of ground cover and makes the floodplain less valuable habitat for many ground-dwelling mammals (Fredrickson 1979).

403. Fredrickson (1979) voiced the opinion that levees were a good alternative to channelization for flood-control projects. Floods are contained by levees, and some floodplain habitat is preserved in the battured lands. Battured lands are less likely to be cleared for agricultural production than the protected floodplain. Fredrickson also recommended that battured lands be placed in public ownership.

Land-use changes

404. The effects of reduced flooding on landside floodplain plant and animal communities are sometimes more drastic than those described above. Frequently, levees constructed on larger streams make channel modification and drainage projects on tributaries feasible by providing outlets (Simons et al. 1975). The drier conditions created by levees and associated channel modification projects are conducive to bottomland clearing and cultivation. This clearing results in a net loss of forested wetlands and an increase in croplands (Klein, Daley, and Wedum 1975). For example, the Mississippi River Valley has experienced a tremendous decline in bottomland hardwood forests over the last century. MacDonald, Frayer, and Clauser (1979) found that bottomland hardwood forests in the Mississippi Alluvial Plain of Arkansas, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee decreased from 11.8 million acres in 1937 to about 5.2 million acres in 1978. During the same period agricultural lands and croplands increased by about 5 million acres. The total study area was 24 million acres.

405. Starrett (1972) reviewed the effects of levees on the ecology of the Illinois River bottomlands. Bottomland marshes and lakes were drained and converted to agricultural land as levees were constructed.

The surface area of marshes and bottomland lakes were reduced by roughly 50 percent for the portion of the floodplain between LaSalle and Grafton, Ill.

Construction and maintenance impacts

406. Some adverse impacts are directly attributable to the construction of the levee structure. Some clearing and floodplain habitat loss is necessitated by the construction of the levee and borrow pits (MacDonald, Frayer, and Clauser 1979). The flat slopes frequently used for levees in rural areas lead to extremely large land requirements for the embankment and berms.

407. Levee vegetation is maintained by mowing, burning, using herbicides, or livestock grazing. All of these methods are aimed at producing a heavy weed-free sod with grass 2 to 12 in. high. Loss of species of plants which provide food can impact some species of birds and mammals. The maintenance of the artificial conditons on the levees can encourage populations of noxious weeds and animal pests. Some species of birds require perches adjacent to streams. Burning produces temporary, local degradation in air quality and the use of some herbicides can have detrimental effects on desirable species. Maintenance of vegetation in certain seasons can displace ground-nesting birds.

Borrow pits

408. Borrow pits may be treated a number of ways after construction. Normally, the borrow pits fill with runoff or infiltrating groundwater. Since control of battured areas is usually returned to a private landowner, the borrow pits may eventually be drained and planted in crops or timber. If borrow pits are not drained, they may provide lakes valuable for fish and wildlife habitat, and recreation. Even borrow pits with gravity drainage will contain water for part of the year.

409. Riverside borrow pits will periodically be flooded by the river, possibly exchanging organisms with the larger system. Thus borrow pits may partially compensate for the loss of other shallow-water areas in the protected floodplain. Cobb and Clark (1980) found that borrow pits composed 4 percent of the riverine aquatic habitat along a

50-mile study reach of the Lower Mississippi River during low to medium flows. During high flows the borrow pits were inundated by main channel waters and accounted for 8 percent of the riverine aquatic habitat. The area of riverside borrow pits may decrease as the pits gradually fill with sediment deposited by floods.

Aesthetic impacts

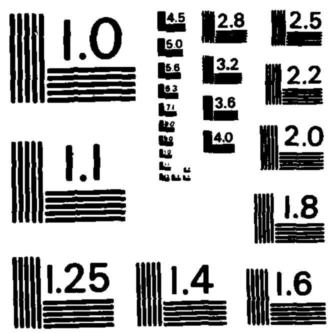
410. The aesthetic or visual impacts of a levee system must be stated in subjective terms since perceptions vary with the individual. Levees may be thought of as a negative influence on the aesthetic value of an area since their massive form, regular geometry, and low vegetation are unnatural to a floodplain environment. On the other hand, levees offer some visual diversity to floodplains devoid of topographic relief and provide overlooks of the river and battured areas. Borrow pit lakes may have some aesthetic value, but their regular dimensions tend to look artificial (Ryckman/Edgerly/Tomlinson and Associates 1975). Floodwalls may have a more pronounced impact than levees since they are usually built in urban areas and since they are less natural in appearance than levees. They usually block a waterfront view from an urban area. In some cases hinged floodwalls have been built to reduce negative aesthetic impacts.

## Recent Developments

411. Recent efforts to enhance the positive environmental impacts of levees include management of vegetation on levee embankments, berms, and battured areas. Some work has also been done on development of recreational areas associated with levee projects.

Management of vegetation

412. Public concern for environmental values has prompted several investigations addressing the problems of management of vegetation at levee projects along the Sacramento River (Davis, Ito, and Zwanck 1967, MacClanahan et al. 1973, Mifkovic and Petersen 1975). Traditional maintenance of Sacramento River levees consists primarily of removal of all significant vegetation from the levee by burning, spraying herbicides,



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

or clearing. Studies conducted by the California Department of Water Resources have shown that with proper maintenance, certain species of shrubs and plants may be allowed to grow on the riverside slope of the levees without adversely affecting the integrity or effectiveness of the levee system. The studies also recommended that stands of vegetation between the riverside toe of the levee and the water's edge should be allowed to remain as long as they do not reduce adequate flow capacity.

413. The studies of vegetation on Sacramento River levees have also shown that maintaining levees with plantings costs roughly twice as much as traditional levee maintenance (MacClanahan et al. 1973). Instead of burning or using herbicides, the planted slopes require mowing, removal of dead trees and shrubs, and removal of debris deposited by high water. Trees must occasionally be trimmed and topped.

414. In addition to increased maintenance costs, effective management of vegetation on and adjacent to levees requires additional expenditure for environmental easements. Public acquisition of easements on levees and battured lands is necessary to prevent private landowners from grazing livestock on levee embankments and berms and cultivating battured areas. If the general public is expected to bear the costs of easements and vegetation planting and maintenance, they may want to have access to levees, and providing public access may require additional expenditures (Davis, Ito, and Zwanck 1967).

415. Plant species selected for levee slopes should be tolerant of flooding and drought, provide protection against erosion, and have both aesthetic and wildlife habitat value. Ideally, the plant species selected for levees should discourage burrowing rodents and encourage their predators. Plantings should be arranged with large shrubs and trees spaced well enough to allow visual inspection of the levee and with low growing species planted dense enough to reduce erosion (Davis, Ito, and Zwanck 1967, MacClanahan et al. 1973).

416. Ground squirrels dig deep, intricate tunnels into levees along the Sacramento River and thus create maintenance problems. In the past, eradication of squirrel populations has required removal of vegetation on the levees to expose burrows. The vegetation is normally burned

off or killed with herbicides. Ongoing research indicates an integrated program of vegetation management, trapping, and smoke bombing might provide more effective control of ground squirrel populations with less adverse environmental impact. Species of vegetation beneficial to ground squirrel predators and detrimental to ground squirrels could be cultivated, while those species providing food and cover to the ground squirrels could be eliminated. This approach to managing pest populations requires planting and selective maintenance of levee vegetation.*

## Summary

417. Levees are earthen embankments that furnish flood protection from seasonal high water. Levee projects include the main embankment, berms, borrow areas, and appurtenant features to handle seepage and interior drainage. Structural bank protection is sometimes required on riverside slopes. Levees may be enlarged with additional earth fill or raised using concrete floodwalls.

418. Existing CE design and construction guidance for levees is found in EM 1110-2-1913 (U. S. Army, Office of the Chief of Engineers 1978a). Guidance for landscaping levees and berms is found in EM 1110-2-301 (U. S. Army, Office of the Chief of Engineers 1972). Existing levee design practice is primarily concerned with the soil mechanics of the foundation and available fill material and with analyzing potential seepage patterns through the levee section. Environmental considerations are not presently a major element of levee design.

419. Levees are constructed by methods that may be categorized as compacted, semicompacted, or uncompacted. Current construction practice generally employs typical heavy earthmoving equipment. Levees are usually turfed or seeded after construction. Borrow areas may also be planted.

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* Center for the Integration of the Applied Sciences of the John Muir Institute. 1978. "Third Written Report from the Integrated Pest Management Project of the John Muir Institute to the Department of Water Resources," Grant No. B52750, Berkley, Calif.

420. Levee maintenance and operation is normally the responsibility of local sponsors. Maintenance and operation must be performed in accordance with Federal regulations. Levee vegetation is maintained by mowing, burning, livestock grazing, or spraying herbicides to produce a heavy sod 2 to 12 in. high. Large vegetation, such as trees or shrubs, is not allowed on levees except that which is planted specifically for recreation or aesthetics. Levees must be patrolled continuously during periods of high water, and immediate action must be taken to correct any condition that endangers the levee.

421. Adverse environmental impacts of levees may be classified as either short- or long-term. Short-term impacts are associated with levee construction activities: clearing, grubbing, stripping, and borrow and placement of fill material. Short-term impacts of levee construction are similar to the environmental impacts of any large-scale earthmoving project. Long-term impacts may be divided into impacts of the levee system on river hydraulics and floodplain hydrology, and impacts due to the placement of the levee structure.

422. Levees have two main impacts on river hydraulics. By confining overbank flows to a narrower cross section, they increase the stage for a given overbank flow over the stage for a similar flow under unleveed conditions. Since the floodplain acts as a storage reservoir, levees increase peak discharges for overbank flows by eliminating storage in the protected floodplain. The influence of other channel modifications and structures on river hydraulics and the lack of reliable historical hydrologic data make it difficult to assess the significance of the influence of levees on river hydraulics.

423. Levees create a wetter regime on the riverside and a drier regime on the landside. These changes in hydrologic regime can cause changes in the species composition of plant and animal [illegible]ties. Even more important, the drier conditions on the landside [illegible]cate clearing and cultivation of forested wetlands in the protected floodplain. Forested wetlands are valuable for several uses and are a rapidly diminishing resource. In some cases the wetter conditions on the riverside discourages cultivation and development enough to provide a haven

for flood-tolerant plants and animals. Riverside borrow pits that fill with water provide aquatic habitat.

424. Recent developments in levee design, construction, and maintenance include new approaches to managing vegetation on levee slopes, embankments, and in battured areas. Investigations at levee projects along the Sacramento River have demonstrated the utility of certain types of trees and shrubs on levees. However, maintenance of levees with special plantings was found to cost significantly more than levees with no trees or shrubs. Control of burrowing animals on Sacramento River levees is being studied to produce alternatives to traditional methods, which involve burning or use of herbicides to remove all vegetation.

## PART VII: CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

425. Existing CE and national policy mandates full consideration of environmental quality in planning, design, and construction of Civil Works waterway projects. Although extensive general guidance now exists regarding environmental goals and objectives, there is a shortage of specific, technical design and construction guidance to implement these environmental policies.

426. The type and magnitude of environmental impacts associated with CE waterways projects are largely determined by decisions made during the planning process. Innovative design alternatives and construction methods that reduce adverse environmental impacts should therefore be considered during the planning process as well as during the later phases of a project.

#### Flood-control channels

427. The nature and magnitude of environmental impacts of flood-control channel modifications vary considerably from project to project. In general, however, it may be stated that the ecological impacts of a given channel project are related to intentional or unintentional changes in the physical characteristics of the stream. Physical changes that usually have adverse environmental consequences include reductions in channel sinuosity, vertical relief, substrate size, and channel stability. Changes in water quality and in the depth and velocity of flow are sometimes also related to adverse environmental impacts. Channel alignment or relocation frequently leads to a reduction in the amount of aquatic habitat and land-water interface. Aesthetic impacts are usually related to a loss of visual diversity.

428. Environmental guidance for flood-control channels should therefore provide methods for increasing the flow-carrying capacity of stream channels while minimizing changes in the physical characteristics of the stream. Relocated, aligned, and enlarged channels should have physical characteristics that provide habitat for a stable, diverse

biological community. Extreme channel instability is undesirable from both hydraulic and ecological viewpoints. Reductions in the amount of aquatic and riparian habitat should be avoided.

429. Considerable innovation will be required in the design and construction of flood-control channel modifications to reduce unfavorable environmental impacts of future projects. An interdisciplinary approach involving expertise in both stream biology and ecology and various fields of engineering will be necessary to produce design guidance for channels that are effective, economical, and environmentally acceptable.

Navigation channels

430. The adverse environmental effects of modifying navigable streams have not been identified as well as the effects of modifying smaller streams. This situation is partially due to the fact that it is more difficult and costly to collect biological data from large rivers than from small streams.

431. Immediate and gradual reductions in the amount of backwater habitat (and thus a reduction in the overall habitat diversity of the riverine system) are major impacts of many navigation channel modification projects. Cutoff meanders, for instance, are frequently isolated from the river and filled in by sedimentation. A stabilized river channel is not free to migrate and create new backwater areas as old ones fill in.

Dikes

432. The major environmental impacts associated with dikes are the reduction in the areal extent of aquatic habitat and loss of habitat diversity due to sediment accretion in the dike field. However, dike structures and dike fields provide valuable habitat for fish and macroinvertebrates until they are covered with sediment. The rate of sediment accretion in the dike field varies considerably from site to site. Scour channels, pools, chutes, and submerged bars may be maintained in dike fields perpetually by natural or man-made causes, and remain valuable aquatic habitat. Minor and temporary environmental impacts are associated with dike construction activities.

433. Notches may be cut in dike structures to maintain enough

flow through the dike field to reduce the rate of sediment accretion. New dikes may be constructed with lower crest elevations or with a gap between the structure and the bank. Evaluations of notched dikes on the Missouri River indicate that the notches create flow conditions which maintain desirable shallow-water habitats. Dike notching on the Missouri and Middle Mississippi Rivers has not adversely affected the navigation channel.

Streambank protection

434. Major adverse environmental impacts associated with streambank protection include the loss of riparian vegetation and reduction in the rate of channel migration. Riparian vegetation is important to both the terrestrial and aquatic communities, as well as to the aesthetic value of the stream. Large-scale channel stabilization projects can lead to reductions in aquatic habitat and habitat diversity. Stream length is reduced when channels are maintained in shorter alignments. Habitat diversity is reduced when the rate of channel migration is reduced so that new backwater areas are not formed as old ones are silted in.

435. Some streambank protection projects have favorable environmental impacts. Improved water quality can result from reductions in turbidity and sediment concentration. Some types of bank protection provide stable substrate for macroinvertebrates and cover for fish. Scenic resources may be improved or degraded by streambank protection.

436. Environmental considerations for design and construction of streambank protection projects include local and basin-wide effects on riparian vegetation and stream morphology. Streambank protection structures subject to prolonged inundation should be designed to provide desirable aquatic habitat.

437. The use of native species of flood-tolerant plants shows promise as a method of protecting upper banks and areas of low erosional stress. Existing information allows the flood tolerance of many plant species to be quantified. Well-designed vegetational bank protection may be effective, economical, and beneficial to aquatic and terrestrial communities and add to the aesthetic resources of the stream. Regions

of high erosional stress usually require structural protection.

438. One type of streambank protection design that holds promise for reducing adverse impacts is based on a vertical zonation of the streambank according to frequency of flooding. Structural protection is used for the toe and selected flood-tolerant vegetation is used on the upper bank.

Levees

439. The most significant adverse environmental impact of levee systems is related to the main purpose of levees, the prevention of flooding. The creation of drier conditions on the protected floodplain frequently leads to the conversion of forested wetlands to agricultural lands. This impact is probably best addressed by preservation of selected tracts of floodplain in a natural state, and not by changes in current levee design practices.

440. Potential exists for enhancing the positive environmental impacts of both existing and future levee projects by development of borrow pits and battured areas for recreation, aesthetics, and fish and wildlife habitat. Potential also exists for increased use of vegetation on levee slopes and berms, but additional work is needed to develop economical planting and maintenance techniques harmonious with levee maintenance for flood control.

## Recommendations

441. Detailed design and construction guidance should be developed that incorporates environmental considerations in order to implement existing CE policies.

Flood control channel modifications

442. Future research on environmental considerations for flood control channel modifications should include:

a. A systematic survey of conservation agencies and agencies involved in design and construction of flood-control channel modifications to identify innovative designs and construction techniques that may be used to reduce adverse environmental impacts.

b. Detailed biological and engineering evaluations of existing channel-modification projects that incorporate features to reduce environmental impacts.

c. Definition of the relationships between stream and floodplain biology and hydraulic performance of erodible channels.

Navigation channels

443. Information about the ecology of large rivers should be used as input to design and construction of navigation projects. Desirable habitat characteristics and physical conditions producing such habitats should be identified. Desirable habitats and habitat diversity should be maintained and created. Long-term changes in the amount and diversity of riverine habitat should be monitored and controlled.

Dikes

444. Standard dike designs should be modified in order to maintain and create desirable habitats. The actual manner in which dike systems produce given physical changes in the riverine system is not well understood. However, qualitative information concerning specific dike designs and resulting accretion patterns could be developed using available potamology data. This information could then be used as a first step in development of improved guidelines for design and construction.

445. Results of the waterways field studies, other ongoing or planned studies concerning environmental impact of dikes, and studies concerning basic hydraulic design parameters for dikes should be used in the development of environmental quality guidelines. Environmental guidance for dikes must be compatible with the purposes of dikes, the maintenance of adequate navigation depths and a stable channel alignment.

Streambank protection

446. Methods should be devised to evaluate the effects of streambank protection projects on basin-wide stream morphology and channel stability. More information is needed on the long-term effects of channel stabilization and the resulting reduction in the rate of channel migration on riverine ecosystems.

447. The types of structures and construction materials that

provide valuable aquatic habitat with minimum damage to the riparian community should be identified. Bank protection techniques that preserve and enhance riparian vegetation should be evaluated and documented. Greater attention should be given to the use of native flood-tolerant plant species, particularly on upper banks. Criteria for plant species selection should include habitat value, aesthetics, flood tolerance, and erosion resistance.

Levees

448. Economical planting and maintenance techniques for vegetation on levee slopes and berms should be developed that allow the use of plant species valuable to wildlife. Such planting and maintenance techniques should be harmonious with levee maintenance for flood control. Concepts for recreational developments associated with levee projects should be compiled and evaluated.

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# APPENDIX A: CLEARING AND SNAGGING GUIDELINES FOR WOLF RIVER SYSTEM*

## General Guidelines

1. No stream work, including bank clearing and excavation or removal of materials, should be allowed except at specific locations where significant blockages occur. Channel excavation and snag removal should be accomplished with the minimum clearing possible to provide access to the stream.

## Materials to be Removed from the Channel

### Log jams

2. Only those log accumulations that are obstructing flows to a degree that results in significant ponding or sediment deposition should be removed.

### Other logs

3. Affixed logs. Isolated or single logs will not be disturbed if they are embedded, jammed, rooted or waterlogged in the channel or the floodplain, are not subject to displacement by current, and are not presently blocking flows. Generally, embedded logs that are parallel to the channel are not considered to cause blockage problems and will not be removed. Affixed logs that are crossways to the flow of waters in the channel and are trapping debris to the extent that could result in significant flooding or sedimentation may be removed.

4. Free logs. All logs that are not rooted, embedded, jammed or sufficiently waterlogged to resist movement by river currents may be removed from the channel.

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* Guidelines developed by several government agencies and private organizations. Similar guidelines are being used on the SCS Chicod Creek Watershed project in North Carolina and are planned for two additional projects in Tennessee. From McConnell et al. (1980).

Rooted trees

5. No rooted trees, whether alive or dead, should be cut unless they are leaning over the channel at an angle greater than 30° off vertical and they are dead or dying or have severely undercut or damaged root systems or are relying upon adjacent vegetation for support and it appears they will fall into the channel within one year and create a blockage to flows; or their removal from the floodplain is required to secure access for equipment to a point where a significant blockage has been selected for removal.

Small debris accumulation

6. Small debris accumulations should be left undisturbed unless they are collected around a log or blockage that should be removed. (It is felt that small debris accumulations will not constitute a significant blockage to flows and upon removal of logs and other blockages under these guidelines and following completion of the project, the changed water velocities would remove and disperse these small debris accumulations so that no significant blockage of water flows will result.)

Sediments and soils

7. Major sediment plugs in the channel may be removed if they are presently blocking the channel to a degree that results in ponding and dispersed overland flow through poorly defined or nonexistent channels and, in the opinion of appropriate experts, will not be removed by natural river forces after logs and other obstructions have been removed.

## Work Procedures and Equipment to be Used

Log removal

8. First consideration will be given to the use of hand-operated equipment to remove log accumulations. When the use of hand-operated equipment is not feasible, vehicled equipment may be used under the following restrictions and guidelines:

a. Water-based equipment (e.g., a crane or winch mounted on a small, shallow draft barge or other vessel) should be

used for removing material from the streams. A small crawler tractor with winch or similar equipment may be used to remove debris from the channel to selected disposal points.

b. When it can be demonstrated that stream conditions are inadequate for the use of water-based equipment, the smallest feasible equipment with tracking systems that minimize ground disturbance will be specified for use. Larger equipment may be employed from nonwooded areas where cables could be stretched down to the channel to drag out materials to be removed.

c. Access routes for equipment should be selected to minimize disturbance to existing floodplain vegetation, particularly in the riparian zone. Equipment should be selected which will require little or no tree removal to maneuver in forested areas.

Rooted trees

9. Whether dead or alive, rooted trees selected for removal shall be cut well above the base, leaving the stump and roots undisturbed. Procedures for removing the felled portion will be the same as for other logs.

Log disposal--general

10. All logs or trees designated for removal from the stream or floodway shall be removed or secured in such a manner as to preclude their re-entry into the channel by floodwaters. Generally, they will be transported well away from the channel and floodway and positioned parallel to the stream channel so as to reduce flood flow impediment. Where large numbers of logs are removed at one location (e.g., log jams), burning may be the most feasible disposal technique. Burying of removed material should not be allowed.

Sediment blockages

11. The magnitude of the blockage such as the one in the vicinity of Moscow, Tenn., necessitates the use of conventional excavating equipment. This equipment should be employed in a manner which will minimize environmental damages, as follows:

a. Access routes for equipment should be selected to minimize disturbance to existing floodplain vegetation, particularly in the riparian zone.

b. Material disposal and necessary tree removal should be limited to one side of the original channel at any given location.

c. To the maximum extent possible, excavating equipment should be employed in the channel bed.

d. Where feasible, excavated materials should be removed from the floodplain. If floodplain disposal is the only feasible alternative, spoil should be placed on the highest practical elevation and no material should be placed in any tributary or distributary channels which provide for ingress and egress of waters to and from the floodplain.

e. No continuous spoil pile should be created. It is suggested that no pile exceed 50 ft in length or width and a gap of equal or greater length should be left between adjacent spoil piles.

f. Spoil piles should be constructed as high as sediment properties allow.

g. The placement of spoil around the bases of mature trees should be avoided where possible.

## Reclamation Measures

12. All disturbed areas should be reseeded or replanted with plant species which will stabilize soils and benefit wildlife. Revegetation should be in accordance with recommendations of the Biology Work Group.

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